DEVELOPMENT AND CHARACTERIZATION OF AN EMERGENCY COMMUNICATIONS SYSTEM USING NEAR VERTICAL INCIDENT SKYWAVE ANTENNAS

THESIS

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Abstract
The NVIS system characterized in this work was designed to eliminate skip propagation by optimizing the design for contiguous coverage. The NVIS technique involves use of transmission and receiving antennas that create nearly vertical propagation and continuous coverage from the transmitter to a distance of 200 miles. Man portable, very low power transceivers (5 watts maximum) and horizontal dipole antennas five feet above the ground are used in an NVIS communication system for this work. The system is designed for the purpose of supporting communication with emergency workers in areas where other communication is difficult. Digital and analog effectiveness are compared at this low power range, and the human factors of communication error are described.

Subject Terms
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AN EMERGENCY COMMUNICATIONS SYSTEM
USING NEAR VERTICAL INCIDENT SKYWAVE ANTENNAS

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To my fellow amateur radio operators, and especially to Mr. Frank Beafore, I can offer only to continue to learn and share, toward the benefit of the general advancement in amateur radio experimentation.

To the gentlemen of my thesis committee I owe deep thanks for the hours they spent in helping me formulate and clarify what I would say in this thesis. Dr. Mike Temple, went beyond this by helping me to chart a course for the last 18 months of my part-time education.

Research in areas where there is little published literature moves from the impossible to the possible with the enormous storehouse of information using the Internet. Unfortunately, that storehouse has an effervescent quality of impermanence to it as well. I have referenced a number of Internet resources in this document, but only when there was no known bound reference available. For those who may tread in my footsteps, the chair of my thesis committee within the Air Force Institute of Technology will maintain a paper copy of the Internet sites.

I would also like to introduce the thesis by noting the information here is useful to the Electrical Engineering, Medical and Amateur Radio communities. I have tried to write so these words are readable by all three.

Richard A. Allnutt

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List of Abbreviations

AM – Amplitude modulation

BBC – British Broadcasting Corporation

BPSK – Binary phase shift keying

COTS – Commercial off the shelf

CW – Continuous wave, i.e. Morse code

FEC – Forward error correction

FM – Frequency modulation

HF – High frequency

HT – Handheld transceiver

LOS – Line-of-sight

M – meter

MF – Medium frequency

MFSK – M-ary frequency shift keying

MFSK16 – COTS MFSK program which includes convolutional encoding and interleaving

MHz – megahertz

MUF – Maximum usable frequency

NEC – National electromagnetic code

NVIS – Near vertical incidence sky wave

PSK31 – COTS BPSK program for personal computer

PVC – Poly-vinyl chloride

RF – Radio frequency

SSB – Single side band

SWR – Standing wave ratio

UHF – Ultra high frequency

VHF – Very high frequency

WS8B – Amateur call sign of Mr. F. Beafore

WS8G – Amateur call sign of Dr. R. Allnutt

Abstract

Near Vertical Incident Skywave (NVIS) techniques involve physical propagation using the electromagnetically reflective canopy of ionosphere. HF radio transmission is normally optimized for distances beyond 1000 miles. However, NVIS techniques optimize communication from the transmitting station out to 200 miles.

A void exists in communication distances beyond line-of-sight and closer than several hundred miles. Line-of-sight communications can easily be accomplished with transceivers operating above 90 MHz. Long distance communication around the globe can be accomplished with HF radios, however HF communication is frequently disrupted by the peculiar nature of skip propagation. Skip propagation is the tendency for HF waves to be received in the immediate vicinity of the transmitter and also received several hundred miles away, but to be missing (skipping) the interval between. This is the result of optimizing the design of HF antennas for long distance communication.

The NVIS system characterized in this work was designed to eliminate skip propagation by optimizing the design for contiguous coverage. The NVIS technique involves use of transmission and receiving antennas that create nearly vertical propagation and continuous coverage from the transmitter to a distance of 200 miles.

Man portable, very low power transceivers (5 watts maximum) and horizontal dipole antennas five feet above the ground are used in an NVIS communication system for this work. The system is designed for the purpose of supporting communication with emergency workers in areas where other communication is difficult. Digital and analog effectiveness are compared at this low power range, and the human factors of communication error are described.

DEVELOPMENT AND CHARACTERIZATION OF
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I. Introduction

September 11, 2001 was a watershed date for military men and women in the United States. The thinking and planning for this thesis had progressed through the spring and summer of 2001, but with the "Attack on America" in September, the importance of techniques for emergency communication gained new importance and interest. This exploration of an unusual and little researched communication technique, i.e., the use of near vertical incidence skywave (NVIS) propagation, poses immediate usefulness to a society dependent on technologically advanced communication prone to sabotage and disruption.

There is a long history of military and commercial aviation use of HF radios. While military HF applications have diminished, the standard worldwide means of tracking long, over-water, commercial aircraft flights remains HF communications [9].

In some communities, HF communications is often viewed as an outdated, difficult, and unreliable mode for communicating. It does have its share of problems, including fading, dependence on the solar cycle, and a high noise background induced by atmospherics [30]. However, there are attributes of HF communications which are well matched to new digital capabilities developed with other purposes in mind, but which can easily be made to work with HF waves [32, 37].

As mentioned above, the limitations of radio communication involve radiated power, distance and obstacles. It has been said that the finest transceiver is useless without a practical and efficient antenna. This is because effective radiated power (ERP) depends on an efficient link between transceiver and free space [33]. Antennas for HF transmission are much the same as antennas used in any other frequency band. Varying as a function of wavelength, real antennas of a size necessary for efficient HF transmission normally do not resemble either isotropic or free space models. Dipoles and their derivatives are the primary practical antennas used for HF frequencies [33].

Looking at the practicalities of trying to maximize long distance communication, antennas were developed which emphasize radio wave propagation toward at the horizon. Producing a grazing antenna pattern, often referred to in amateur radio literature as having a *low take-off angle*, is best achieved using either a vertical antenna, utilizing a reflective ground plane to create a virtual dipole, or a horizontal dipole located as far away from the earth as possible [34].

A side effect of emphasizing long distance communication is the production of skip propagation. Skip propagation is the tendency for HF waves to be received in the immediate vicinity of the transmitter (line-of-sight and ground wave) and also received several hundred miles away, but to miss (skip) the interval between [30].

Near Vertical Incidence Skywave (NVIS) techniques involve a physical propagation technique using the electromagnetically reflective canopy of the ionosphere [24]. While all HF communications can reflect from the ionosphere, as well as the earth's surface, HF radio transmission is normally optimized for distances beyond 1000 miles [35].

NVIS techniques attempt to optimize communication over ranges of 20 to 200 miles. Instead of radiating most energy from the HF antenna at a grazing angle, the primary lobe of radiated energy is raised toward the zenith. These techniques are based on the common use of HF radio waves, but the novel techniques involve using antennas optimized for nearly vertical propagation. Instead of aiming for long distance, contiguous short distance communication is the goal [15, 23].

The NVIS communication techniques purposely attempt to circumvent the generation of skip propagation, making medium distance communication possible. By design, the direction of propagation in azimuth and elevation can be selected. The resulting antenna pattern produces spatial selectivity – enhancing some signals while rejecting signals on the same frequency whose propagated waves are received from other directions[1].

Antennas designed to work effectively at long distances direct their energy at a small grazing angle relative to the earth's surface. Waves propagating beyond the visual horizon continue to the ionosphere where a portion of the energy is reflected back toward the earth [24]. The reflection from the ionosphere's electrons is quasi optical and away from the transmitter. An area of skip propagation can be formed between the horizon and the point where the reflection again reaches the earth [30]. The propagating wave is actually refracted and dispersed during its interaction with the ionosphere. There is no physical altitude of actual reflection. Instead, an apparent altitude of reflection can be calculated which is actually at a greater altitude than the more curved path taken by the electromagnetic wave during propagation [30].

Conversely, if the antenna is designed to direct its radiation in a solid cone primarily oriented upward and perpendicular to the earth's surface, the apparent reflections are primarily downward. Communications can be maintained beyond the visual horizon with no area of skip. Such antennas can be used to allow communications to literally "leap" tall mountains and escape from urban canyons where UHF and VHF transmissions are absorbed by building materials [15].

There are complexities in designing of NVIS systems [6], including a host of issues involving ionospheric reflectivity at different times of day and the sun spot cycle [24]. Practical antennas need to be considered [9]. The form of communication, analog versus digital, needs further exploration [35]. It is these details that form the body of this work.

Objectives

Within this thesis, the described history of NVIS communications leads naturally to new explorations involving digital techniques. Specifically, an experiment comparing analog voice communication with two digital techniques is described in detail. Using simple antennas designed to optimize NVIS communications, an experiment using very low power HF radios is developed and reported. This experiment allows comparison of the relative merits of newer digital techniques with the analog NVIS communication systems developed by the US Army and radio amateurs.

Methods

The Federal Communications Commission sponsors the Amateur Radio Service, among other reasons, to allow experimentation with communication techniques. The NVIS experiment conducted as part of this research, takes place within the radio spectrum available for such an experiment by United States Amateur Radio Operators [30]. The author is licensed by the FCC as an Amateur Extra class licensee with a call sign of WS8G. As a partner in these explorations, another radio amateur, Mr. Frank Beafore, WS8B acted as the station control operator of a second station for the experimental work. Transmissions were made at very low power (5 watts) and from different locations purposely chosen for their difficult terrain obstacles. Throughout the research, data was collected with the expectation of reaching a conclusion regarding the practicality of the digital modes, as presently available, with analog voice communication by an experienced radio operator.

Terminology

Certain specialized terms are important to the understanding of these concepts. As already described, Near Vertical Incident Skywave (NVIS) antennas are used. Technically, an NVIS antenna has a far field radiation pattern that is directed primarily in a cone normal to the earth's surface. Practical NVIS antennas have an antenna pattern which if visible would look much like a rather tall puffball mushroom [9].

Dipole antennas are used extensively in this research. Normally, they are half wavelength dipoles implemented as physical wires horizontally oriented. The wires are connected to the transceiver via 50-ohm coaxial cable and are unbalanced wire antennas pruned to have a minimum Standing Wave Ratio (SWR) for a specific frequency. Occasionally, crossed dipole or loop antennas are introduced, both of which are also be horizontally oriented [33, 34, 35].

Analog communications refers to voice communication using standard single side band (SSB) techniques on the lower side band of the frequencies considered here [34]. Two types of digital communications are considered. Binary phase shift keyed (BPSK) transmissions using a published protocol known as PSK31 uses a frequency band about 30 Hz wide. A personal computer program generates the signal [12, 25]. Using another program, 16-Ary multiple frequency shift keying (MFSK) with convolutional coding/decoding and interleaving, is tested with a protocol known as MFSK16 [10, 19, 20].

Equipment

To the maximum extent possible, commercial-off-the-shelf (COTS) materials and equipment are used in this work. The HF radios were manufactured and certified for amateur radio use by Yaesu and are designated the FT-817. Operating on 9 to 12 volts with either an internal battery or external battery, the units are capable of transmitting at several power levels between 0.5 and 5 watts [13].

All communications were accomplished on the 40-meter (7.000 to 7.230 MHz) amateur radio bands. More than one band needs to be available to deal with cyclic changes in propagation. Operator experience (and the application of several *rules of thumb*) leads to making the proper frequency choice [30]. Voice communications were made via the lower sideband using standard single sideband techniques [33]. Digital signals were created by an interface with a personal computer. The personal computer ran *freeware* versions of PSK31 and MFSK16 programs available over the internet. The computer program for the selected digital mode drives the computer's standard sound card (Soundblaster® 16) to create (or analyze in receive mode) the audio frequency signal. The audio signal interfaces the microphone and headphone jacks of the radio. The communication link was half-duplex; i.e. the radio was either in receive or transmit mode at any time [11].

To make comparisons between the different modes, a set of standard words was used to determine the ability to receive with accuracy. This set of words is developed from the audiology literature and from the aviation medicine practice [31]. It is used by flight surgeons to determine a pilot's performance in understanding aircraft radio communication. Several similar lists are used with order effects controlled. The same lists were used for the spoken audio (analog) and for the digital modes. In each case, the receiving radio operator chooses between similar sounding (reading) words using a multiple choice score sheet. In addition, for the digital words, a raw score of character errors was calculated from a direct comparison of the ASCII transcripts of the digital mode sessions [31].

The antennas used for this research are dipole antennas incrementally designed by the author using commercial antenna modeling software [28]. Derivatives of the very simple half wavelength dipole antenna, they have been primarily modified by being placed close to the ground. During the incremental design process, the goal was finding a balance between take-off angle and radiated power could be made by adjusting the height of the dipole above the ground. To decrease the effect of ground wave and multipath canceling, the antenna was designed to minimize ground wave at some expense of total radiated signal strength [1].

II. Background

Propagation

NVIS propagation can be described as a new way of thinking about an old subject. Radio engineers have been using NVIS techniques for many years, though much of their work has been directed toward ways of decreasing NVIS propagation.

Early in the history of radio, professionals and amateurs learned methods of promoting over-the-horizon propagation of HF radio waves. A low *take-off angle* in the antenna used by the transmitter and receiver promoted long distance communication. The means of this long distance communication was gradually understood to be ionospheric reflection of the HF radio waves [33].

The use of electromagnetic waves for communication parallels development of science in the western world [17]. Beginning with spark gap transceivers and continuous wave transmitters, communication techniques progressed to amplitude modulation, suppressed carrier, frequency modulation, and digital communication techniques. The communication efficiency is dependent on distance, radiated power, and obstacles between transmitter and receiver [35].

Frequencies used for communication literally span the spectrum from audio to light [17]. Early commercial analog communications were conducted at what is now called the medium frequency (MF) band – commonly known as the AM radio spectrum. Commercial broadcasters encouraged the government to allocate the high frequency (HF) spectrum above MF to amateur experimentation, believing these frequencies were essentially worthless for commercial use. World War II brought military development and use of higher frequency bands for communication. Introduction of the klystron tube made high power transmission above 100 MHz practical. Practical use of Very High Frequency (VHF), Ultra High Frequency (UHF), and other bands used early for radar and later for communication was a byproduct of military development [30].

Electromagnetic waves essentially propagate along straight paths. Like light, they propagate until they are absorbed, reflected, or refracted. The consequential limitation of line-of-sight (LOS) communications becomes apparent as an uninterrupted line of sight is lost. Many children have played with handheld transceivers (HTs) and experienced one of the most discouraging limitations of these HTs, namely, the loss of signal occurring very soon after one user loses visual sight of the other. The primary limitations of low, fixed power transceivers is the same as all transmitters- radiated power, distance, and obstacles. But when one goes around the school building, the primary limitation becomes the obstacle. If the obstacle is too dense, or contains much metal, the signal is lost [1].

One way to limit the problems of LOS communication is to put one or both users at an elevated location, i.e., put one user on top of a hill or tall building. Such a simple maneuver can extend the maximum effective range of HTs from less than a mile to many miles. As elevation eliminates LOS obstacles, the range limitation becomes a function of the radiated power [35].

Line-of-sight communications can easily be accomplished with transceivers operating above 90 MHz. This includes everything from commercial FM radio to VHF and UHF. VHF, and later UHF, transceivers were developed during WWII for the military, but are now ubiquitous in amateur, business, and personal communications [35].

Similar, but not identical, to LOS communication is ground wave propagation. Classic experiments have shown that light, and by extension, radio waves diffract around corners. The amount of energy diffracting around a corner is dependent on the physical nature of the corner and the radio wave. Different materials, different shapes and different wavelengths all impact the actual behavior of the diffraction. Over the varieties of undefined terrain surrounding a radio user, it is clear that energy propagates around corners that one can not see around. The corner may be a gentle hill, an ocean wave, or for a short distance, the nautical horizon. Whatever the physical nature of the corner, this kind of communication link can be thought to be primarily ground wave communication [35].

The usefulness of ground wave propagation increases with wavelength. VHF and UHF have very little ability to bend around hills and buildings. One very nice property of MF transmission is the extent to which the waves can propagate along the ground. It is this specific property that made MF AM signals, a commercial broadcaster's dream. A reasonably high antenna and relatively high power can be used to reach a very large audience, well beyond the LOS region. The *clear channel voices* of the major cities can still be heard well beyond the nautical horizon [34].

The early MF commercial broadcasters did not recognize the potential for sky wave communication. Giving the *short wave* frequency bands to amateurs, many of them thought the HF bands would always be useless. Prone to large amounts of static interference from atmospheric lightning discharges occurring hundreds (or thousands) of miles away, the potential to use the HF bands for communication was strongly discounted [30].

The long distance properties of HF radio waves begin with the earth's ionosphere. Starting at an altitude of about 40 km, and stretching to several earth radii, the ionosphere is a charged region consisting of ionized particles stripped of their electrons by solar radiation. The ionosphere is a region of low winds, high temperature (with almost no gas mass to transmit that temperature to solids) and very low pressure. Depending on the time of day, season, and the amount of solar radiation, it forms layers (primarily electrons) which reflect HF radio waves [24].

Amateur radio operators, given the HF bands for experimentation, soon found that long distance communication around the globe could be accomplished with HF radios. Between 3 and 30 MHz, intercontinental communication is often practical at reasonably low power levels[30].

The founding experiments of long distance radio communication were focused on communication with ships at sea and with intercontinental radio. The primary official focus was on communication with ships, as there were legal disputes between those who wanted to use radio waves to communicate between North America and Europe and those who had paid to lay intercontinental wire on the floor of the Atlantic Ocean [30].

Successful long distance communication requires choice of appropriate frequencies to exploit the radio reflective canopy of the ionosphere [24]. Medium frequency waves, such as those used by commercial AM radio transmitters in the frequency range 0.5 to 1.5 MHz are of most use as direct LOS and extended ground wave communications. At very high power, and especially at the higher end of the spectrum, these waves can be heard between cities several hundred miles apart. In the 1930s, a set of *clear channel* voice radio stations with power levels of up to 500,000 watts were used by commercial radio broadcasters [33]. The author's father remembers hearing AM signals from WLW in Cincinnati (500,000 watts) detected by bedsprings in New Orleans, Louisiana. In the 1930s, lying in bed in the quiet of the night, familiar radio stars could be heard coming from the metallic springs under the mattress! On a somber note, medical anecdotes of people being hospitalized in psychiatric hospitals for schizophrenia (voices in their head) were later found to have actual voices emanating from dental fillings acting as AM radio detectors. (Always ask someone who hears voices if they also hear music or radio station call signs.) Later, the *clear channel voices* of New York, Chicago, Cincinnati, and Los Angeles were limited to 50,000 watts and reports of incidental AM detection decreased [33].

Very short waves are also of limited use for long distance communication on earth [30]. VHF and UHF (and higher) frequencies are of most use in line of sight communication. They penetrate the ionosphere easily and are used in extraordinarily long distance communication between earth and far-flung satellites at interplanetary distances [7]. But on earth, these signals are normally stopped by the first thick physical horizon made of rock, dirt, or metal [1]. Within these ranges, lower frequency signals are able to penetrate man made (non metallic) structures, while at the upper ranges, even household building materials become a significant barrier to radio waves. At the lower end, the ionosphere can occasionally reflect signals near 50 MHz. Signals near 150 MHz can occasionally be propagated well over the horizon by tropospheric ducting (atmospheric wave guide) or briefly by ion scatter created by meteorites. But at the higher end, 400 MHz into the low GHz ranges, physical objects become more and more opaque and reflective of radio waves. For these reasons, most use of these waves is line-of-sight. Portable communications in these frequencies often assume the form of handheld transceivers (HTs and cell phones) of very low power output in the range of less than 10 watts [30].

Ground level VHF, UHF, and microwave communications between handheld devices is inherently limited to distances of only several miles [34]. These distances can be extended indefinitely with the use of high towers and dedicated radio repeaters [34]. Amateurs, business band users, and cell phone companies all use this repeater concept to add range to what is an essentially short-range method of communication. Aircraft based VHF and UHF communications can be of long distance because the physical horizon is at a great distance when the aircraft is at cruising altitude. For specialized operations, repeaters can be aircraft or spacecraft based, allowing long distance communication at the expense of keeping the aerospace vehicle off the ground and overhead [7].

Between the upper frequencies of medium wave AM and the lower edge of VHF, there is possibility of reflection of radio waves off the high altitude ionosphere. The ionosphere begins at 40 km and extends to several earth radii of altitude. The ionosphere was first described by experimental soundings at a group of worldwide locations. It has been shown that the reflective planes of mainly electrons change their altitude and characteristics on both a daily and seasonal basis. Solar events also affect the characteristics of the ionosphere. The ionosphere is essentially the product of the interaction of the gasses of the atmosphere with high-energy particles and electromagnetic waves created by the sun.   Thus, most events that change the solar radiation of the earth change the ionosphere. These changes have profound effect on ionospheric reflection of radio waves [24].

Changes in the ionospheric conditions and the condition of solar radiation are known as *space weather*. Space weather changes much like earth weather. There are episodic storms each of which is not open to direct prediction. There are also a number of cyclic changes that can directly be predicted in time if not in extent [30].

The daily shift from day to night dramatically changes the condition and altitude of radio reflective layers of the ionosphere. As the day dawns, energy from sunlight changes the ionosphere so that the Maximum Usable Frequency (MUF) rises. The shift of seasons likewise brings changes to the ionosphere. The increased length of the day and greater angle of incidence of sunlight on the ionosphere leads to a higher MUF [24,30].

The 11 year solar sunspot cycle, recorded for the last several hundred years, also contributes dramatically to the activity of the ionosphere, with elevated sun spot numbers leading to a higher MUF and generally better conditions for HF reflection [24, 30].

These space weather phenomena are subject to some prediction or at least the application of several rules of thumb. An HF radio operator on a commercial airliner knows that lower frequencies will *work* better at night and early in the morning. Higher frequency bands will be more useful as the morning ends and through the evening. Summer months allow the use of higher HF frequencies in either the northern or southern hemisphere when contacts are made within the hemisphere. Spring and fall are the seasons of choice for long distance communication across the equator. Radio amateurs follow with great anticipation the development of each sunspot cycle as radio propagation steadily improves in the first half of a cycle and then wanes in the nadir of the cycle [[30].

Sunspots make their own individual contribution to HF radio conditions as markers of specific solar events. A visible group of sunspots (visible about 8 minutes after they appear - given the distance of the sun from the earth and the speed of light) may lead to a particle event several days later that has its own independent effect on HF radio propagation through interaction with the earth's magnetosphere [24]. During intense magnetic storm conditions, HF radio communication that relies on reflection from the ionsophere may be entirely shut down for several hours. The same magnetic storm may cause considerable damage to orbiting satellites and health risks for astronauts outside the protective lower levels of the magnetosphere [7].

By the 1940s, the transatlantic radio service was well established and ship-to-shore communication had been expanded to include communication with intercontinental air service [34]. Commercial and government short wave radio stations around the world have heavily depended on high frequency communication. Such broadcasts never gained the following in the United States that they did in other countries. Nevertheless, the US has many faithful followers of the BBC *Worldwide Broadcasting Network* [30].

Part of the attraction of the short-wave broadcasts is their availability at great distance. This distance was achieved by the propagation methods alluded to previously. Essentially, they depend on skip to get their message over the horizon [35].

All of which led to a study of skip and improved scientific understanding of the propagation method. Informally, skip is the tendency of HF radio waves to be heard well at great distance while they cannot be received at an intermediate distance [30].

There are two factors that lead to the skip phenomenon. The first is the direction the transmitting and receiving antennas have their main beams pointed. The second may involve optical principles that approach total internal reflection [1].

As briefly stated earlier, early emphasis in HF radio was in promoting long distance communication. There were other communication forms that would work for short distance. The domain of the HF radio engineer was working out communication between distant outposts [35].

A study of propagation with ionospheric reflection at close range requires consideration of the interaction of sky wave and ground wave signals. For the moment, ground wave signals will be those line of sight electromagnetic waves and those ground wave refracted waves that come to nearby site. This leads to a combination of waves observed line of sight and a bit beyond the visual horizon. HF waves have a tendency to propagate over some hills and small obstructions precisely because they are of long wavelength [24].

In distinction to these ground wave signals, sky wave signals will be those that are received after being reflected off the ionosphere. In NVIS work, the direction of incidence of the incoming HF signal is from nearly vertical [9].

Assuming one can bounce a signal off the ionosphere and a station can receive it several miles distant from the transmitting station, it is possible for the ground wave to block the sky wave by destructive interference [24]. A similar situation exists in VHF and UHF transmissions when signals reflected by structures or delayed by atmospheric events may arrive in phase or out of phase. Often, moving several inches can dramatically affect reception of UHF signals. In mobile service, such reception is sometimes called “picket fencing” because the audio wave received sounds like it is received through a picket fence along the road [30]. Similar effects can cause large changes in cell telephone service well within the expected service range from a transmit site [32].

Such destructive interference can exist when sky wave and ground wave signals arrive slightly out of phase. If it is desired to make use of the sky wave signal to be able to talk over a mountain, into an urban canyon, or to a station 60 miles away, then the antenna design will need to optimize the sky wave signal while working to keep the ground wave signal at a minimum.

The problem with communications based on skip is the transience of communication due to time dependent ionospheric changes. Especially irritating is the inability of hearing stations just over the horizon to a couple hundred miles away [34].

Antennas

Part of the beauty and the headache of antennas used for HF radio work is their size. In an era when electrical engineering design is primarily design of chips or the programming of them, antenna design deals with larger components. These components, the radiating elements and transmission lines, are of such a size that one can hold them in a hand and move them easily. The other enjoyable aspect of antenna design is that experiments can take on an aspect of art where creativity still plays a part [30].

The antennas used for HF transmission and reception (equivalent functions for design) can be elegantly simple. Horizontal half wave dipole antennas have been used for a century. Their equivalent, the quarter wave vertical, is also well described, understood, and widely used [33].

In amateur radio work, commercially available transmitters are almost always designed to expect 50-ohms of impedance at the feed point. The 50-ohm coaxial, shielded cable is the nearly universal transmission line between the transceiver and the antenna. This is reasonable, if properly pruned dipoles or verticals are the antenna system. A minimum Standing Wave Ratio (SWR) near 1.2 to 1.4 can be achieved reducing transmission line heating and loss of power. This SWR is possible because the natural impedance of the free space dipole is 68 ohms and the natural impedance of the quarter wave vertical over a perfect conductor is half of that at 34 ohms [30].

The analytic representation of a horizontal dipole antenna has previously been characterized. The direct component of the horizontal dipole has an electric field E_q as shown here:

$$E_q \approx jh \frac{I_O e^{-jkr}}{2pr} \left[\frac{\cos\left(\frac{p}{2}\cos q\right)}{\sin q} \right]$$

where I_O is the current maximum,
h is the intrinsic impedance of the medium,
r is the distance from the antenna, and
q is the angel of observation from the y axis (zenith.)

The antenna pattern of a horizontal dipole is a well-described *doughnut* with minima along the axis of the antenna. Nearer the ground, the pattern becomes more and more distorted by reflection and coupling, until a greatly diminished hemispherical pattern exists as the dipole is brought very close to the ground [1].

Because of the physical size of the quarter wave elements, other methods have been used to reduce the real estate required for the antenna. Elements can be shortened by adding inductors in the mid span of the antenna or capacitance hats at the distal ends of the antenna. These maneuvers have two undesirable consequences. They decrease the efficient bandwidth of the antenna by affecting its Q and reduce the radiation efficiency of the antenna [33]. Another approach can be used to decrease the size of the antenna: A square loop can be employed, decreasing the longest dimension of the antenna by 30 percent [1].

If the troublesome aspects of skip are partly the result of designing antennas to produce a grazing angle near the horizon, then designing antennas to have a high *take-off angle* may be one method to reduce the impact of skip. If the take-off angle can be modified to be more nearly vertical, then energy with the potential of reflection off the ionosphere will arrive with the angle necessary to communicate at close range. Skip will have been eliminated by the simple expedient of not putting anyone within two hundred miles in a skip zone [9].

With care in the design of HF antennas, certain trade-offs can be made between generation of sky wave and ground wave energy. A very low horizontal antenna will have almost all of its energy directed upwards and very little will be transmitted via ground wave. Unfortunately, severe restriction on the generation of ground wave carries the price of absorption of a considerable fraction of the output power by the ground, which may be as close as a fiftieth of a wavelength above the ground [22].

Because of the absorption of power by the ground in NVIS systems, most operators have used transmitters at or above 100 watts. There is no prior experience in the literature showing low power NVIS to be practical [16].

Thought has been applied to the concept of using directional antennas or arrays to point more of the signal upward. Reflectors behind a dipole have been used to increase the signal upward. Unfortunately, to be effective, the reflector needs to be back from the active driven element by something near a quarter wavelength to be effective [1]. Any antenna of this height produces considerable ground wave [6]. For these reasons, no attempt to use finite element analysis models of these arrays was attempted.

Certain practical considerations for a mobile communication system were considered for this system. As discussed in the propagation section, at least two frequency bands need to be available to contend with the state of the ionosphere daytime vs. nighttime [9]. In addition, the same frequency spread will help deal with the annual and 11-year cycles. In the case of the experiments undertaken, the 40 and 80-meter amateur radio bands were chosen. For operational use, frequencies reserved for the military in this part of the spectrum could be just as effectively used [9].

For ease and the sake of simplicity, designs were sought which could use a common transmission line, yet be tuned for use on the two bands. By proactively designing the antenna system for two frequency bands, all question of interaction between antenna systems is resolved. In addition, the radio operator need not change antenna connections when changing frequencies [30].

The intent of this emergency communication system is to be transportable. Changes could be made in the antenna system to allow mobile use, but the antennas would consequently suffer a loss of efficiency as they were made physically short with the use of inductors or capacitors [14].

While transportable, the goal in selecting designs was to work toward the lightest and least complicated designs available. This approach leads to a design that a single individual can carry and erect in a few minutes.

The actual design of the antenna system and the analysis of antenna patterns is contained in the Methods section of this work.

Communication Techniques

Part of the goal of the experimental approach to this topic is to use lightweight, minimal power equipment. The transceiver selected, with internal battery supply, has a maximum output of 5 watts peak power. It is adjustable by steps down to 0.5 watts [13].

In this power range, at distances or in geographic areas that require ionospheric communication, the received signal will be weak. Successful communication in the presence of very weak signals can be aided by skilled operators and by the use of digital encoding procedures [32].

For the purposes of emergency communication, an assumption will be made that the signals need to be sent and interpreted in real time. A number of digital techniques can be used to store and forward information with delay. Certain trade-offs can be made between transmitted power and loss of the ability to interpret a signal in real time. A well-known example of these techniques is used by interplanetary space probes. Very detailed digital images can be collected by a distant spacecraft in rapid order. However, the digital transmission of those images, pixel by pixel, even when compressed, may take many hours or days with redundant error correction techniques [32].

In the case of real-time or near-real time transmission, communications explored here are analog speech signals interpreted by a skilled operator, and digital signals interpreted by an operator.

Digital signals can be of several types. Binary signals can represent the required bit stream by operating on the amplitude, frequency, phase, or several combinations of the transmitted signal [32].

A primitive example of on/off amplitude shifting is continuous wave (CW) signals sent by hand using the Morse Code. Historically, transient spark gap Morse Code signals were the first radio signals sent from one point to another. However, very soon CW Morse signals were being exchanged between distant stations [30].

Binary Phase shift keying (BPSK) was developed for use by spacecraft outside earth orbit. With BPSK, the phase of the signal is abruptly modified . The bandwidth of the signal is directly related to the time domain bit rate driven phase shifts. As the bit rate increases so does the bandwidth required for the signal. Of course, the inverse is also true. As the bit rate is decreased, the necessary bandwidth decreases [32].

One popular digital communication program (PSK31) has aimed for the minimum bandwidth to keep up with typing ASCII characters at up to 50 words per minute. Using a computer sound card to both process the received signal and to generate an audio signal for the transmitter, the transmitted signal is compressed into a 31 hertz. This leads to very effective utilization of the small amount of bandwidth available for experimental use [12, 25].

Other modulation techniques are also available. There are schemes that modulate multiple levels of phase, amplitude, and frequency [11]. One attractive system available for evaluation via the use of computer sound cards employs 16 levels of frequency shifting with convolutional encoding and interleaving [19, 20].

Much is made in the digital communication literature of bit error rate. Bit error rates for various communication techniques can be calculated both on an expected basis and in real time. Bit errors normally roll up into character errors when text is the output of the communication system. These character errors are subject to correction by algorithm and by the skilled user [32].

Encoding a digital signal can allow for error correction by retransmission and also by the techniques of forward error correction (FEC). A number of FEC systems are in use, but the convolutional encoding scheme of Viturbi is a well-described method of correcting the errors that may have been received in the communication system. One COTS program available to the amateur community based on these conditions is MFSK16 [10].

Operations

Much of the over the horizon military communication requirement and emergency communication implementation now depend on the availability of high cost infrastructure. Commercial cell telephone coverage requires a large number of cell telephone towers. These communication nodes are weak points and are distributed widely enough as to make them possible targets for anyone desiring disruption of our emergency response capability [34].

Cell telephone sites are often redundant, with users able to access more than one site [31]. This is good when a small number of users need access over a wide area. However, without a priority access system, a local tragedy can bring the system to its knees. Trunking systems are also prone to failure, just like the cell telephone system, when large numbers of users simultaneously try to access the communication system [32].

Communications are sometimes necessary in emergency operations where no established repeaters are available. The needs of users can be met with aircraft mounted or space based repeaters, but at great cost. This may be feasible over the short term, but becomes less and less attractive for long term communications with rescue or aircraft accident investigation personnel [7].

An aircraft accident investigation team, a hundred miles from a base in an area, and not served by cell telephone service (desert canyons) will have a rough go at communicating with the local military command structure. Aircraft can be used as temporary repeater sites, but become expensive when an investigation lasts more than a few days [34].

A very practical solution to these problems is the use of close-in HF communication with NVIS antennas. Such radio systems with their antennas can be carried by a single individual in a backpack and with solar cell recharging of their batteries can be used indefinitely away from any power grid [8, 9].

There is scant literature on the use of NVIS systems for military operations [9]. Unfortunately, the work that does exist is anecdotal and contains little useful research to allow a planner to understand the engineering concerns or the actual performance of the system [27].

Emergency communication centers using NVIS antennas can be situated in valleys or alleys off the high ground. Long cable runs or the necessity of removing the communication center from the actual area of operations is avoided with NVIS HF communications [8].

Though not specifically addressed in this thesis, there is also possibility of using spread spectrum techniques to additionally complicate the signal jammer's task. Spread spectrum communications are not presently allowed on the HF amateur frequency bands. Therefore, radios that use spread spectrum at HF are not available to amateur operators short of building such radios from scratch. By design, spread spectrum techniques use a wide expanse of frequency, and at HF there are few bands open to investigation [32].

III. Methodology

Overall Configuration

The design constraints for the system include weight, independence from a power grid, and ease of transportation. To be useful as an emergency field communication system, the design constraints led to a back-packable system that could operate on its own batteries for a short time and from the 12-volt system of a vehicle or solar rechargeable battery for extended periods.

Antenna Description

The portable antenna used by WS8G in this experiment is a resonant dipole for 40 meter radio waves, 0.04 wavelengths above random terrain. The antenna was constructed of two lengths of 26-gauge multi-strand copper wire, each 34 feet long. The wires were joined in the center by an insulator made of a two-inch length of poly vinyl chloride (PVC) pipe. The insulator contained a chassis mount female UHF connector (SO-239) with an electrical ground connection on one element of the dipole and the center conductor to the other element.

The center insulator was connected to a 50-foot length of RG-8X 50 ohm coaxial cable using standard PL-259 connectors. The coax was connected directly to the transceiver.

The antenna was supported off the ground by three supports. Each support was made of a 5 foot section of 1 inch PVC pipe, held erect by placing it over a 3 foot section of steel reinforcing rod pushed into the ground and extending about 2.5 feet. Using this method of antenna construction, the antenna system was installed in as little as 5 minutes at each mobile location.

The antenna was tuned before use by *trimming* the distal ends of the dipole by winding up to a foot of excess wire into a tight 1 inch diameter coil. This coil is seen by the system as a nearly infinite resistance to radio frequency energy and eliminates the need to physically remove the wire when tuning for best standing wave ratio (SWR) [32].

Tuning was accomplished with an antenna analyzer, combining a low power oscillator, frequency counter, and an SWR bridge. By design, approximately 1 foot of each end of the antenna required trimming by winding into a terminal inductor. A SWR of less than 1.2 was found for the antenna over all sorts of moist Ohio soil using this technique with a single length of terminal coil. This measurement held over all frequencies used for the experiment – 7.0 to 7.2 MHz.

The antenna used by WS8B at his residence was not optimized for NVIS transmission and was a sloping inverted V antenna. The center point of the antenna is a central insulator 18 feet above the ground. The two antenna legs are spread 100 degrees and the ends of the dipole legs are about 10 feet above the ground. This antenna represents a common instalation of a dipole for long distance communication. Clearly, this antenna falls far short of the goal of getting the antenna at least one-quarter wavelength (33 feet) above the ground. It is actually an NVIS antenna that does little to limit ground wave transmission propagation. This antenna was also tuned for use at 7.0 to 7.2 MHz at a SWR of less than 1.2.

Both antennas represent balanced antennas fed with unbalanced transmission line. No balun (balanced/unbalanced transformer) was used at either station, as this is commonly found by amateurs to be an unnecessary, though theoretically advocated for performance enhancement [32].

The portable unit used by WS8G had a combined weight of about 6 pounds, exclusive of the antenna supports. Two pounds could have been trimmed from this weight by decreasing the length of the coax cable to 15 feet.

RF safety concerns were addressed before using the system. References to regulatory documents showed that minimum distance to the antenna if used at 100 watts at 7 MHz was 1 to 5 feet (depending on antenna gain) even for uncontrolled/public limits [21]. At 5 watts of transmit power, this limit would be several feet closer to the antenna, if any separation was necessary at all. Operators remained at least 10 feet away from the antenna during use, and during mobile use, the control operator made sure all spectators remained more than 10 feet away from the antenna as well.

All research data was recorded during the daytime in December 2001 and January 2002. The phase of the solar sunspot cycle was just past peak, with excellent sunspot numbers. All tests were conducted on the 40 Meter band, though maximum usable frequency was known to be above 28 MHz with sporadic opening to 56 MHz [26].

Transceiver Description

Both stations used the same commercially available transceiver. Designated the FT-117 and built by Yaesu, this small transceiver is designed to work a large frequency spectrum including all of the amateur bands between 1.5 MHz and 450 MHz. Purposely designed for amateurs wanting to use only low power, it produces a maximum of 5 watts of power in the HF bands [13]. For these experiments, the full 5 watts was utilized, though from several locations, it was noted that much less than this power level was required to maintain the communication link.

The transceivers operate on an internal 9-volt battery or on 12-volt external power. Because of inclement weather, the portable WS8G station used a pick-up bed camper with heater. The camper's 12-volt supply was used to power the transceiver, though several hours of use could have been achieved from the internal battery. The fixed WS8G station used the transceiver powered by a home-built, regulated power supply operating off wall (120 volt) current.

Each transceiver is supplied with a microphone and has an internal speaker. For the voice portions of this experiment, the stock microphone and internal speaker were used. The operator set the speaker volume to a comfortable level.

Transceiver and Computer Interface

For the digital portion of these experiments, it was necessary to connect the sound card of a computer to the audio input and outputs of the radio. An interface is necessary in these connections to reduce the voltage of the audio out of the radio and to electrically isolate the devices with transformers. In addition, voltage from a pin of the computer's serial port was required to signal the transceiver when to switch from receive to transmit. Two different interfaces were used. The WS8B station used a commercially manufactured device [36]. The WS8G mobile station used a kit –built interface [29]. Both worked satisfactorily, though the kit built system had a number of advantages including ease of use and cost..

Both operators used lap top computers with internal sound cards. The sound cards were compatible with Soundblaster® 16 standards. Computer processor speeds ranged from 100 MHz to 350 MHz. Both computers ran versions of Windows (98 or 2000) on Intel® Pentium® operating systems.

Antenna Models

The overall design constraint led to early consideration of wire antennas. Wire is portable and lightweight. Surprising large antennas can be erected with field expedient antenna supports or with small plastic supports.

Vehicular antennas for mobile use were not seriously considered for this application. Mobile antennas for HF can be constructed, but these antennas are considerably shortened from the natural quarter wavelength antennas used in this experiment. Physically short antennas can be built with inductive loads or with capacitance hats, but these antennas are inefficient radiators. One of the goals of this experiment was the use of very low power to preserve battery charge and allow backpack portability. Bringing the full size antenna near the ground, to decrease ground wave, causes much of the radiated energy to be absorbed by the soil. Adding further loss by using an inefficient short antenna did not seem to be a reasonable compromise. Vehicular antennas can, and have been used with NVIS propagation, but usually with far more power – at least 100 watts. A vehicle battery in mobile use can sustain this amount of power as long as the motor is running. However, carrying enough battery to use high power for more than a few hours on one's back quickly becomes burdensome [14].

Of full size antennas, four are representative of the primary classes of wire HF antennas. These classes are the vertical, the dipole, the loop and the passive array [33]. All four are classic antennas, and each was modeled for possible use in an NVIS system.

Modeling was accomplished with a commercial *method of moments* application using the NEC II code [2, 3, 4, 5, 28] which is able to deal with up to 30,000 antenna segments and multiple RF sources. Its output consists of both standard tabular NEC results and also a variety of graphic outputs [28].

The vertical antenna modeled was a classic quarter wave ground plane antenna [30, 33]. The specific design was a tuned quarter wave over a plane of 4 intersecting quarter wave wires 4 centimeters above average ground. The author has constructed a number of similar antennas and found the modeling to be predictive of the actual performance of the antenna.

Vertical antennas are normally designed with many more ground wire elements. Several sources recommend up to a hundred such wires in the ground plane [33, 34]. The modeled difference between many wires in the ground plane and a few is very small. Of much more importance is suspending the ground plane an inch or two above the ground. Removing the ground wires from the ground makes them individually much more efficient in improving the radiation characteristics of the antenna [6]. Such a practical antenna can be built by laying 4 ground wires on top of grass. This is also a practical way to build a temporary antenna for portable use.

The specific design input into the NEC program for each of the antennas described here is located in Appendix A. All antennas were modeled with a 50 ohm, unbalanced feed.

The real problem for NVIS work is the antenna pattern of the vertical antenna. The antenna is best used as an omni-directional, long-distance radiator, with peak-radiated power about 24 degrees above the horizon. For the following figure, and all elevation figures in this work, the azimuth is shown when measured at 24 degrees from the horizon. The concentric circles are labeled in dB as compared with an isotropic antenna. The labels are different for each graph and have been scaled to more easily see the difference between antennas.

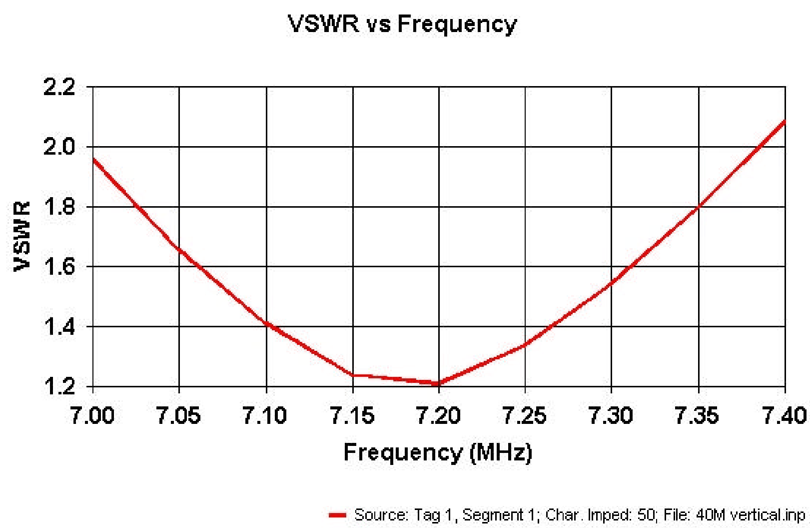


Figure 1. 40 Meter Vertical – 0.1cm diameter vertical element – Standing Wave Ratio

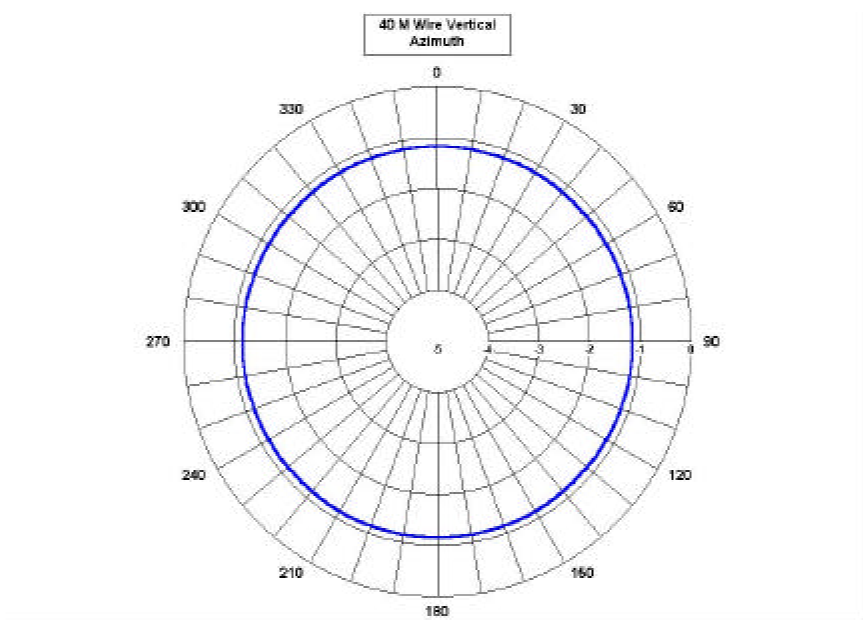


Figure 2. 40 Meter Vertical – Azimuth Field Strength

For the 40 meter vertical antenna characterized here, Fig. 1 shows the efficient SWR achieved by the model. Fig. 2 shows the azimuth pattern, a simple circle. Fig. 3, the elevation pattern shows why vertical antennas are not a good choice for NVIS work. As can be expected, there is very little energy directed toward the zenith.

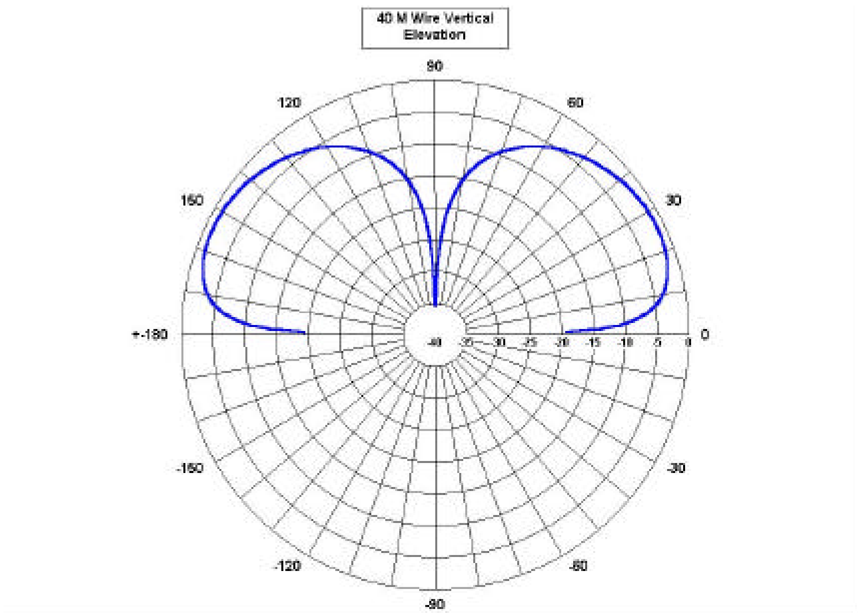


Figure 3. 40 Meter Vertical – Elevation Field Strength

A loop antenna can be used to practically radiate vertically. Such an antenna is a full wavelength in circumference with each of the 4 sides being a quarter wavelength long. Some designers feed the loop from the center of one side. Others feed from a corner. Both have very similar radiation characteristics [3, 33].

Because of a desire to significantly attenuate ground wave propagation of transmitted signals and the reception of ground wave signals originated at another site, both this antenna and the subsequent antennas that are parallel to the ground are modeled quite close to the ground [6, 15].

In an attempt to determine the effects of moving the antenna close to the ground, the antennas were modeled at different practical distances. These distances included a classic quarter wavelength (33 feet at 7 MHz), ten feet above ground, and five feet above ground.

The SWR for each antenna was adjusted by changing the length of the antenna so that best SWR was achieved at 7.2 MHz. As seen in Fig. 4, the best achievable SWR was a fairly poor ratio of 2.6.

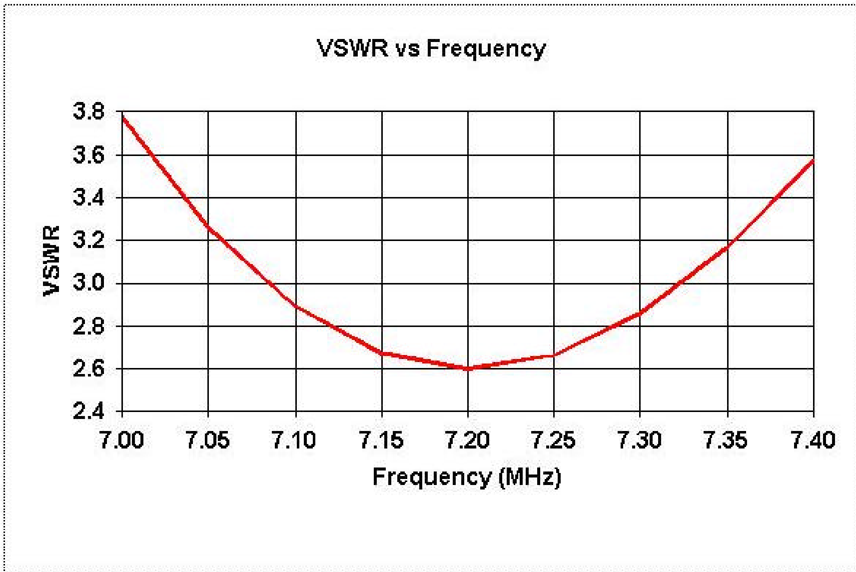


Figure 4. Horizontal 40 Meter Corner Fed Loop – 33 feet above ground – SWR

Fig. 5 shows the SWR for the 10 foot high loop improves to 1.6, while Fig 6 gives an SWR ratio for the 5 foot high loop as about 1.8.

High ratios of reflected energy make a significant impact on the amount of energy radiated from the antenna, as reflected energy, in coaxial transmission line systems tends to be lost as heat.

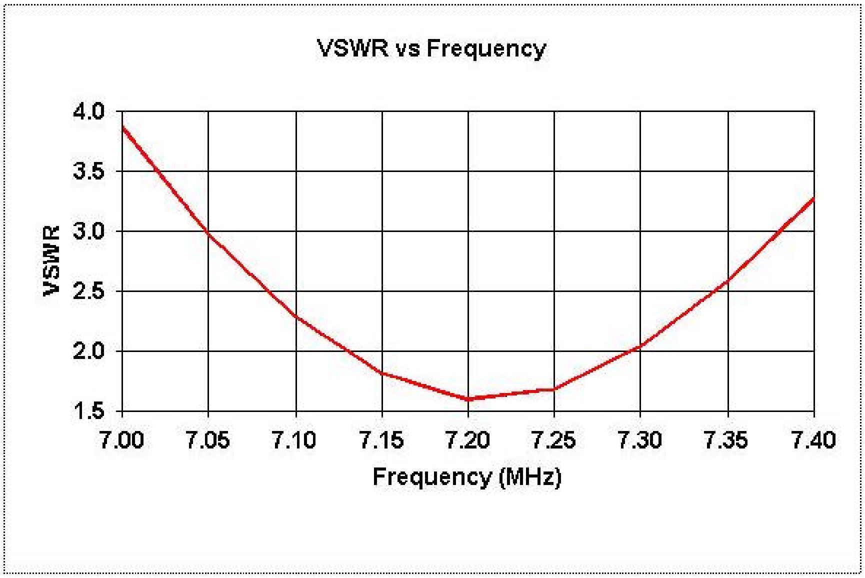


Figure 5. Horizontal 40 Meter Corner Fed Loop – 10 feet above ground – SWR

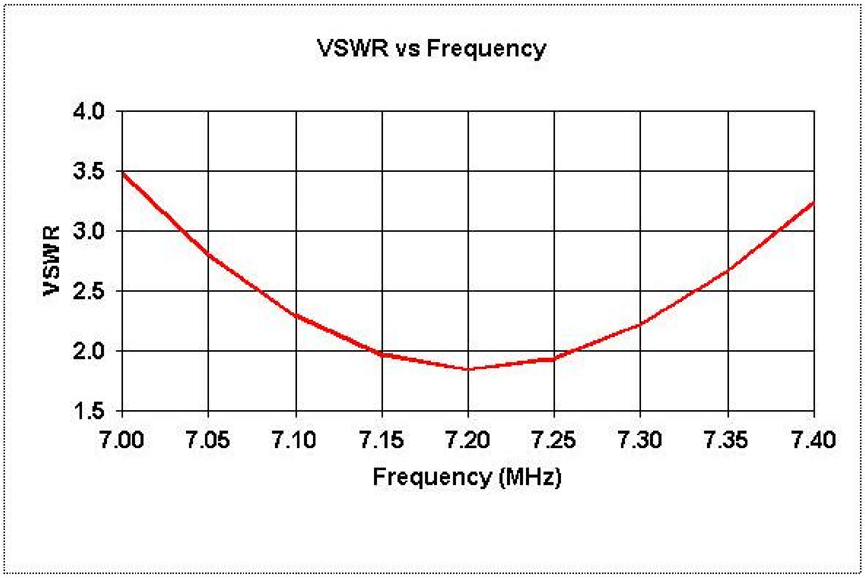


Figure 6. Horizontal 40 Meter Corner Fed Loop – 5 feet above ground – SWR

Next, the antenna pattern for each of these antennas can be compared in azimuth and elevation above the horizon.

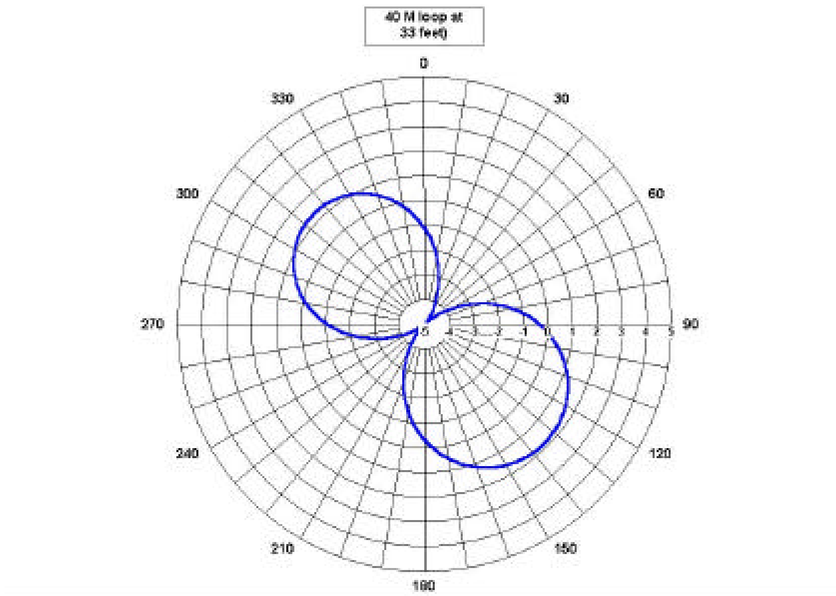


Figure 7. Horizontal 40 Meter Corner Fed Loop – 33 feet above ground – Azimuth

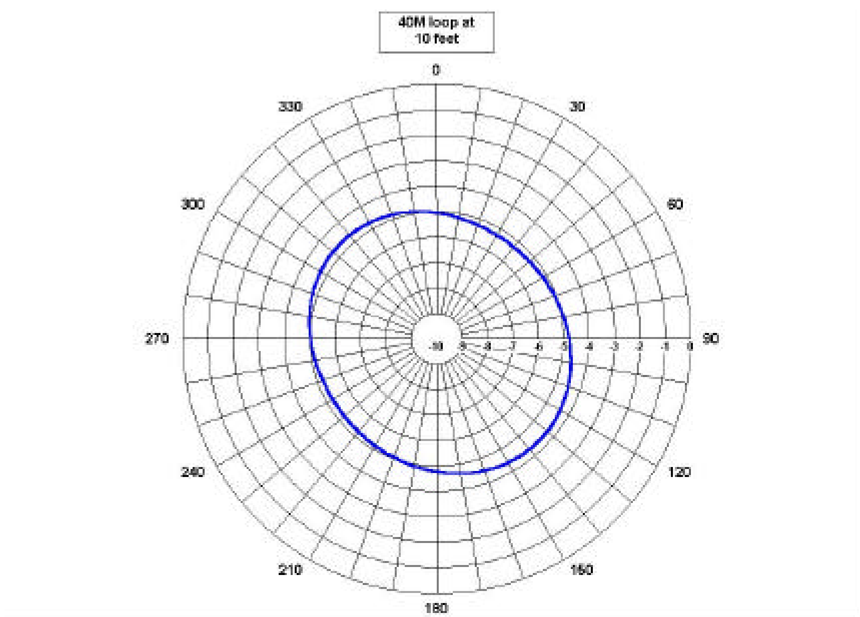


Figure 8. Horizontal 40 Meter Corner Fed Loop – 10 feet above ground – Azimuth

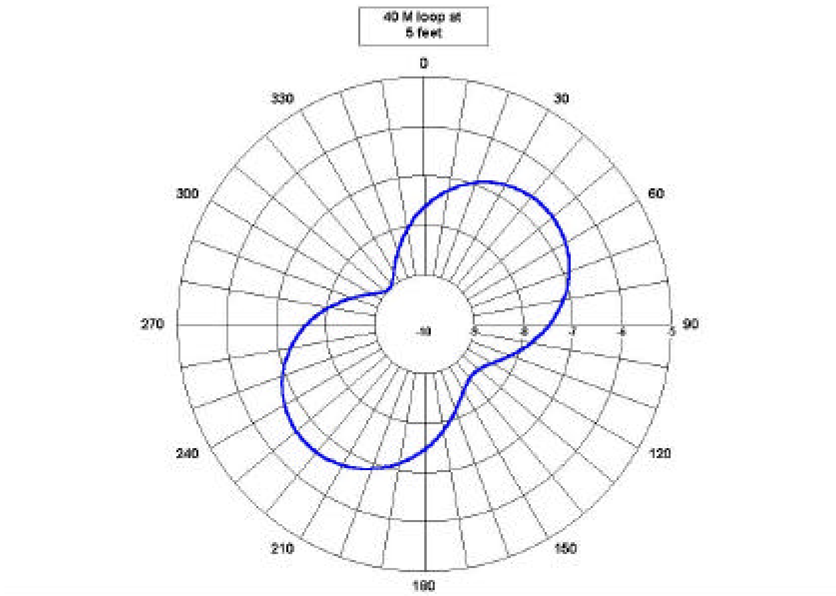


Figure 9. Horizontal 40 Meter Corner Fed Loop – 5 feet above ground – Azimuth

There is a difference in these antenna patterns as the antenna is brought closer and closer to the ground. Fig. 7 shows a close approximation to the ideal antenna pattern of a full wavelength loop. Fig 8. shows the pattern diminishing as the antenna is brought closer to the ground, while Fig 9. shows the pattern down more than 6 dB from isotropic in azimuth. For our practical purpose, it is sufficient to note that the radiated power near the horizon becomes lower and lower as the antenna is brought closer to the ground.

There is also significant difference in elevation above the horizon. It is these comparisons that one finds the balance between ground absorption of the signal while limiting the horizontal reception of the antenna.

Fig. 10 shows the zenith power of a quarter wavelength high loop as about 7 dB above isotropic.

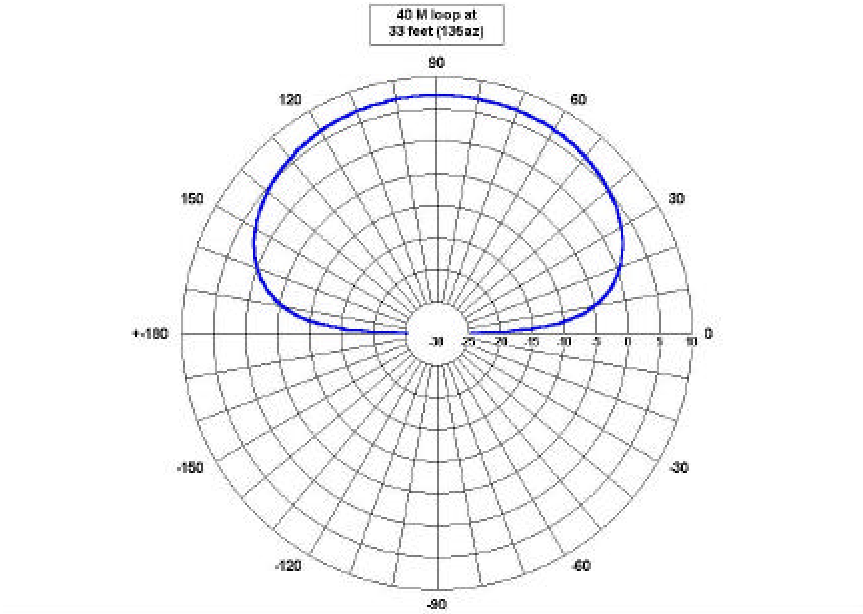


Figure 10. Horizontal 40 Meter Corner Fed Loop – 33 feet above ground – Elevation

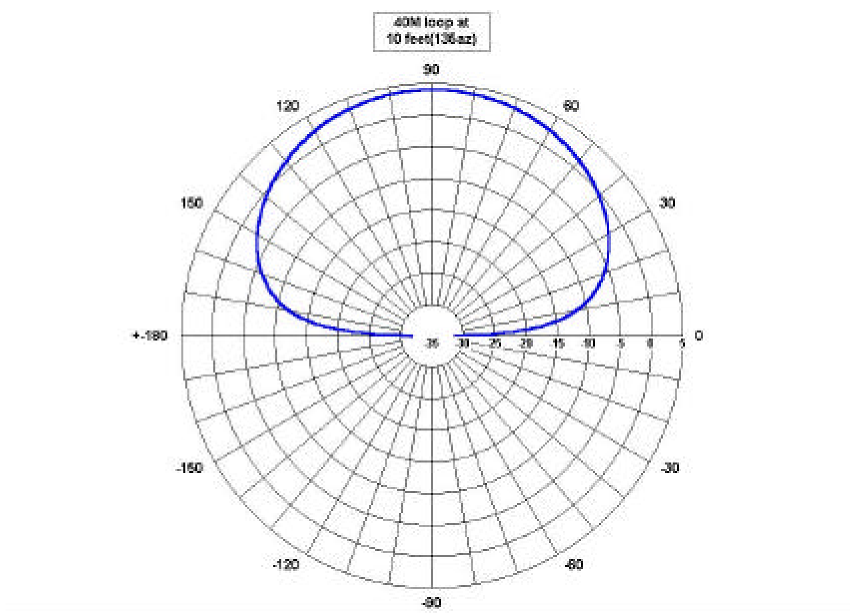


Figure 11. Horizontal 40 Meter Corner Fed Loop – 10 feet above ground – Elevation

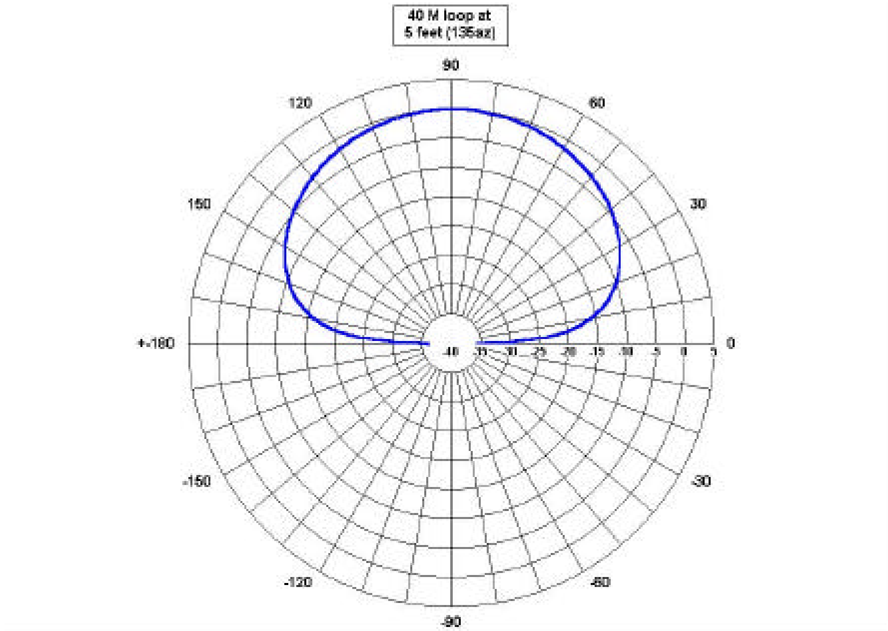


Figure 12. Horizontal 40 Meter Corner Fed Loop – 5 feet above ground – Elevation

Fig. 11 shows the 10 foot high loop is about 4 dB above isotropic, while the 5 foot high version is at isotropic.

A similar analysis of horizontal dipoles follows. The simple dipole is supported above average ground and is modeled as two equal length 1mm wires fed with a 50 ohm unbalanced transmission line. The same modeling is accomplished for the three antennas as in the previous example of the horizontal loop.

The antennas were adjusted for best SWR at 7.2 MHz. The SWR for the antennas was slightly better than the best achievable SWR for the loop antennas.

Figs. 13 – 15 show the SWR for these horizontal dipoles is considerably more favorable than the SWR for the loops. This favorable SWR means less signal power is lost into the transmission line, and more is radiated.

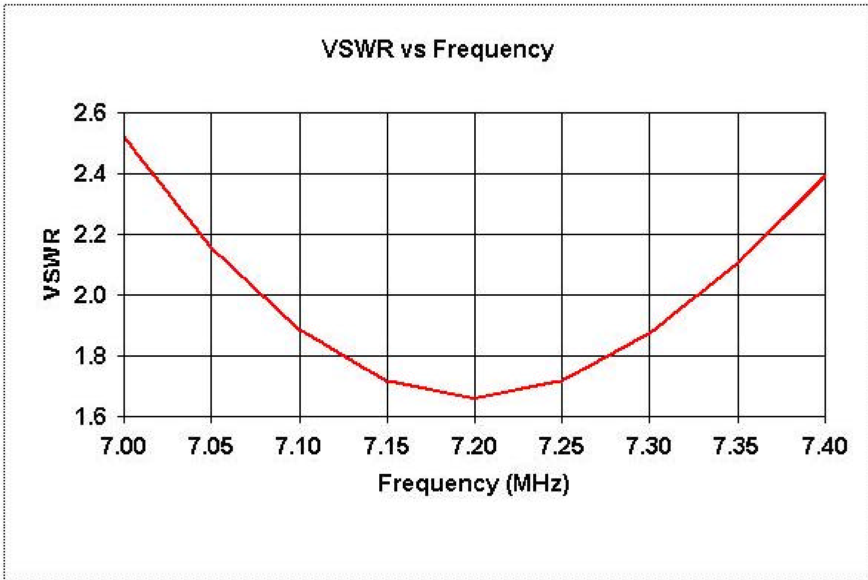


Figure 13. 40 Meter Dipole – 33 Feet Above Ground – Standing Wave Ratio

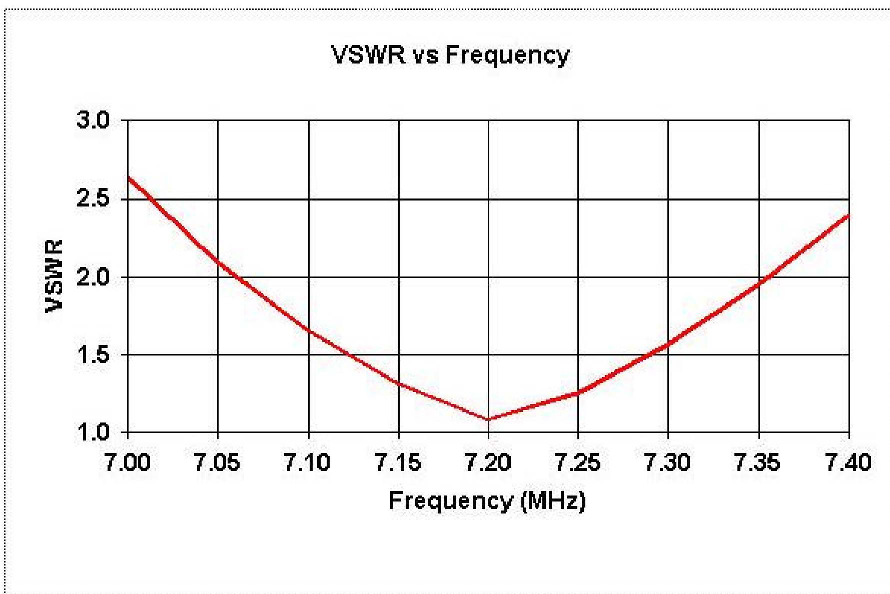


Figure 14. 40 Meter Dipole – 10Feet Above Ground – Standing Wave Ratio

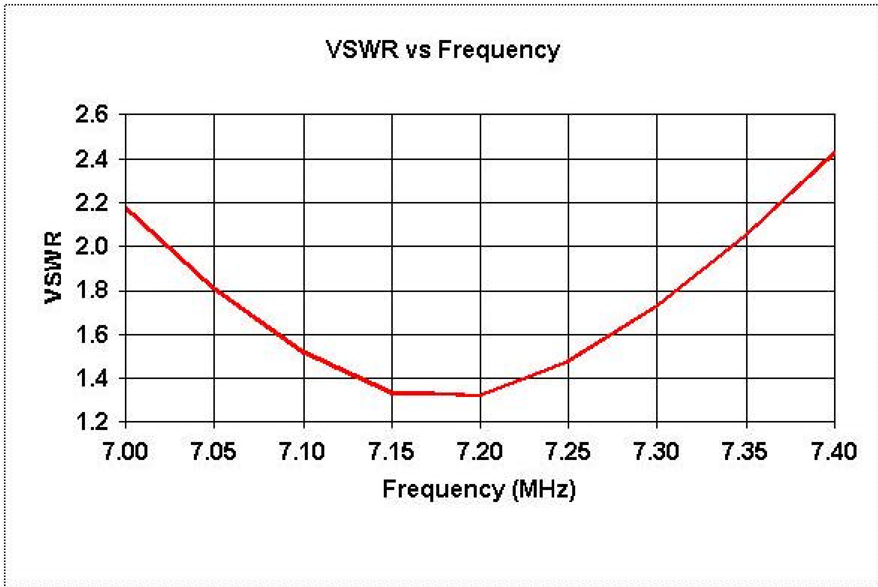


Figure 15. 40 Meter Dipole – 5 Feet Above Ground – Standing Wave Ratio

The azimuth patterns of Figs. 16 – 18, show the same relationship to height above ground that was demonstrated for the horizontal loops. As the antenna is brought closer to the ground, the pattern is distorted and diminished.

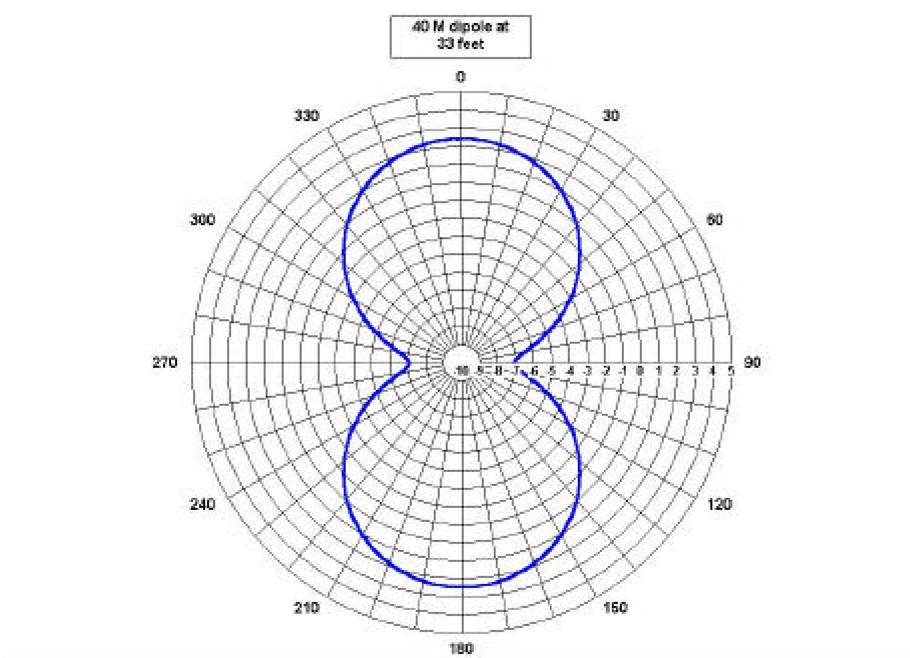


Figure 16. 40-Meter Dipole – 33 Feet Above Ground – Azimuth

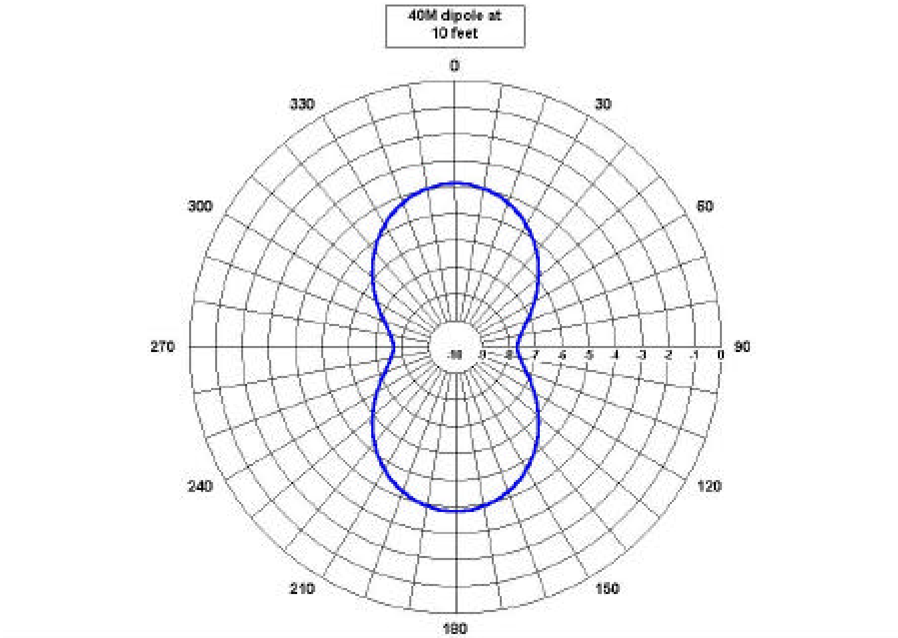


Figure 17. 40 Meter Dipole – 10 Feet Above Ground – Azimuth

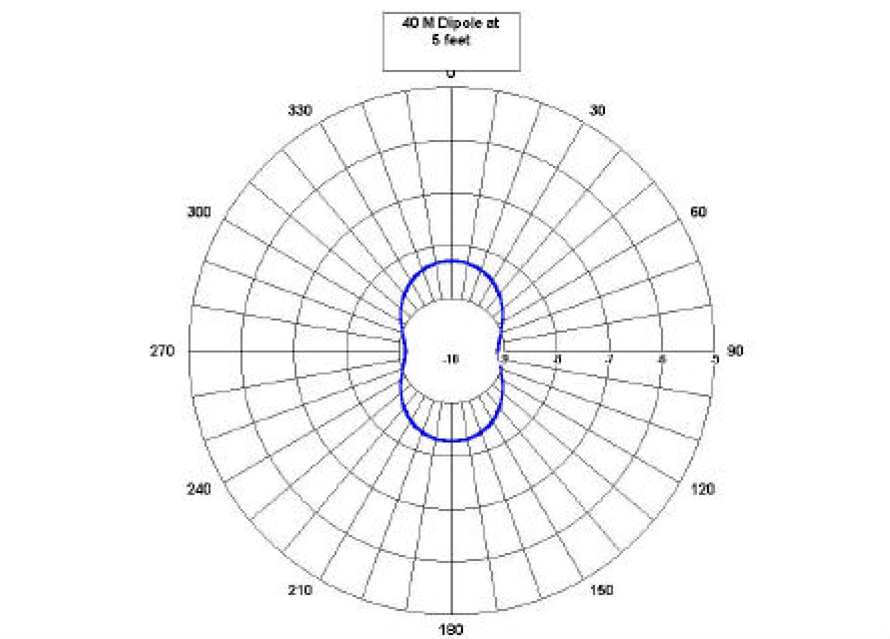


Figure 18. 40 Meter Dipole – 5 Feet Above Ground – Azimuth

In fact, there is a dramatic decrease in the strength of the pattern at a 24-degree elevation as the antenna is brought closer to the ground – from 2.5 to –8.3dB.

In elevation, considerable difference is also seen. Bringing the antenna closer to the ground decreases both the pattern at 24 degrees as well as decreasing the pattern toward the zeinith. However, the pattern (at 5 feet) is more than 6 dB stronger toward the zeinith than toward the elevated horizon.

Fig. 19 shows the vertical radiation to be about 5 dB above isotropic for the dipole a full quarter wavelength above ground.

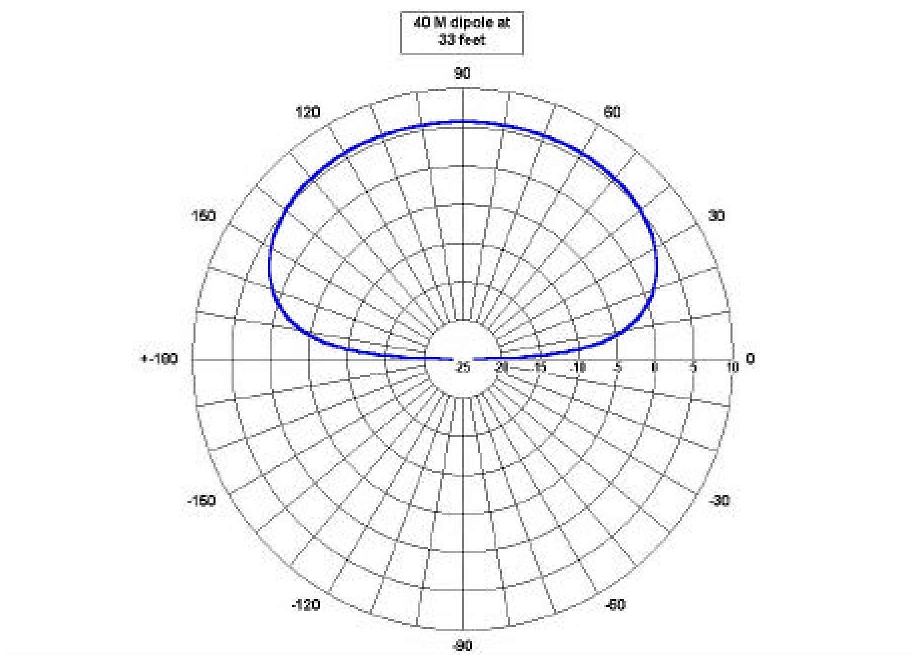


Figure 19. 40 Meter Dipole – 33 Feet Above Ground – Elevation

Fig. 20 shows the radiation upward has decreased to 3 dB above isotropic for the 10 foot high antenna, and Fig. 21 shows the radiation is down to 2 dB below isotropic. This antenna is of note, as the antenna used in the experiments which follow in the thesis.

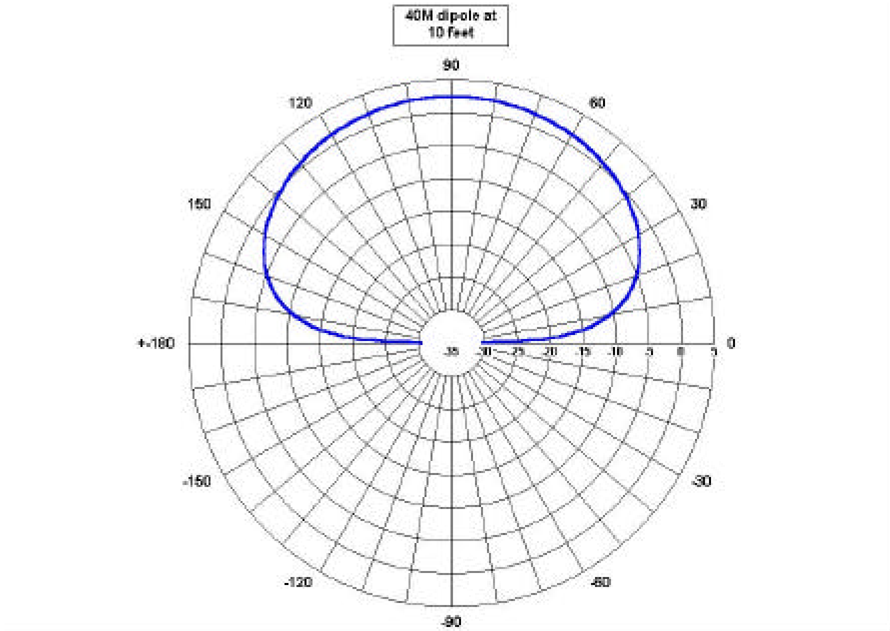


Figure 20. 40 Meter Dipole – 10 Feet Above Ground – Elevation

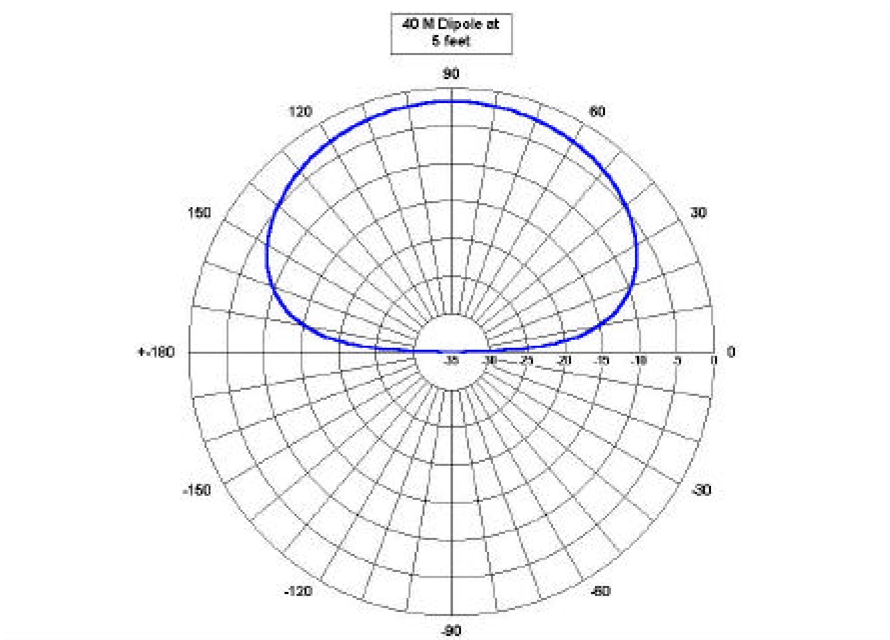


Figure 21. 40 Meter Dipole – 5 Feet Above Ground – Elevation

Note that the strength of the upward directed pattern decreases significantly between each of these steps toward the ground, but the selectivity of only receiving signals from overhead increases at an even greater rate. The difference between maximum vertical component comparing 10 feet with 5 foot heights goes from 3 dB to -2 dB compared with isotropic, about a 5 dB delta. The maximum azimuth strength at 24 degrees above the horizon decreases from –4 dB to –8 dB, a difference of only 4 dB, but resulting in very week reception of signals near the horizon.

The loop antenna's pattern at 5 feet was about 2 dB stronger, but so was it's pattern toward the elevated horizon. Complicating this is the decreased SWR for the dipole – 1.3 vs. 1.8 for the loop. A decision was made to use the dipole based on its simple geometry. Either antenna would work reasonably well [23].

Next, consideration was given to the combination of antennas for two frequencies. With emphasis on simplicity, design of an antenna was begun with a goal of including two bands in one antenna with a single 50 ohm feed line to the transceiver.

Dual band antennas are not uncommon. In vertical, and Yagi beam antennas, radio frequency traps are often placed in the antenna element so that at the higher of two usable frequencies the LC trap acts as a tuned infinite resistance. At the lower frequency, the trap is simply seen as an inductor, shortening the antenna [33].

Fan dipole antennas with separate elements are sometimes used for multi-band HF antennas [30]. Starting with this idea, a crossed dipole antenna was designed for the 40-meter and the 80-meter bands. Such an antenna would allow choice of 40 or 80 meter communication from the transceiver without any change to the antenna system. It is likely that one of these two frequency bands would allow HF communication during nearly every combination of the sun spot cycle, the cycle of seasons, and the diurnal cycle.

The antenna was designed as two perpendicular dipole antennas, in the horizontal plane, joined at the center insulator at which an unbalanced 50-ohm feed was attached. The system was analyzed above a standard ground with the use of the Sommerfield Integral option of NEC Win Plus.

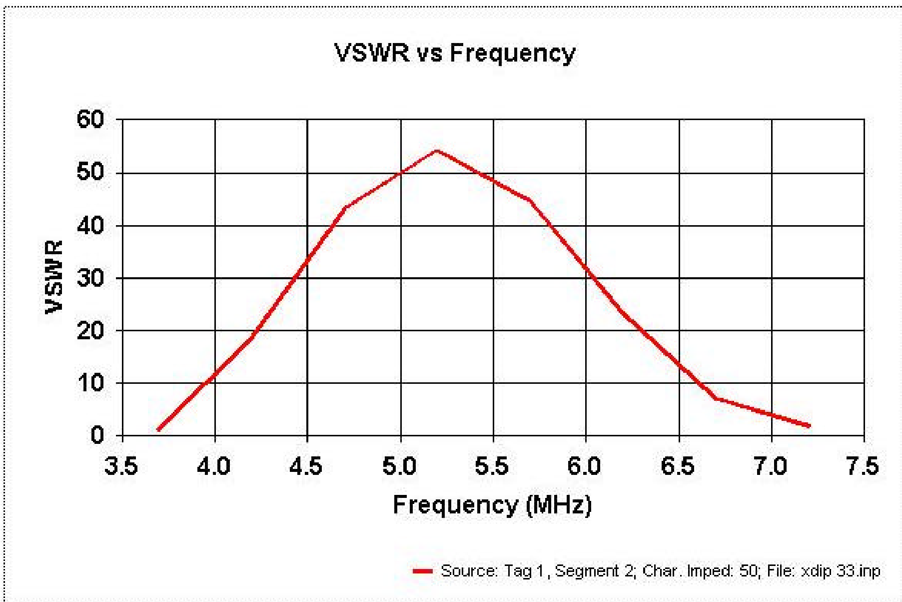


Figure 22. 40-80 Meter Crossed Dipole – 33 Feet Above Ground – Standing Wave Ratio

Fig. 22 shows the frequency response of the dual band antenna at 33 feet. Similar SWR analysis for the ten and five foot high versions are included as Figs. 23 and 24. As designed, the SWR is low at the center of the 40-meter and the 80-meter amateur bands.

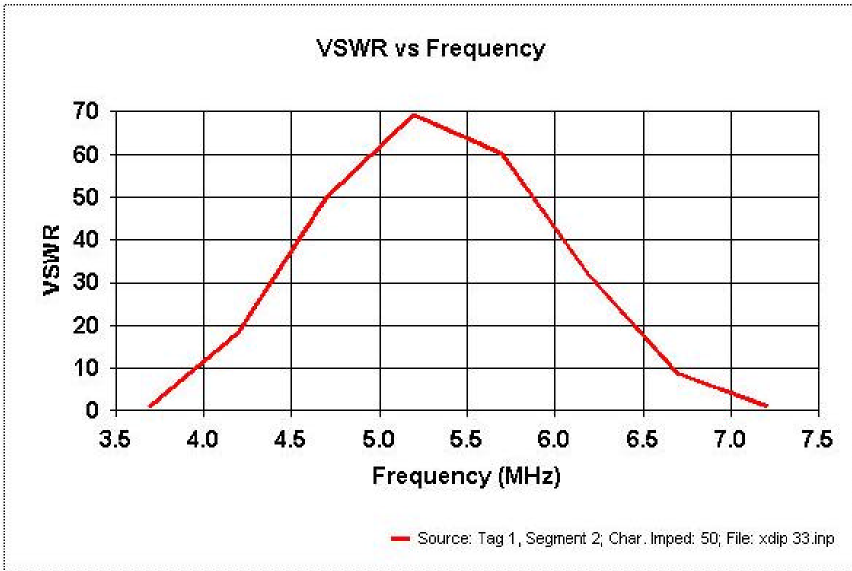


Figure 23. 40-80 Meter Crossed Dipole – 10Feet Above Ground –

Standing Wave Ratio

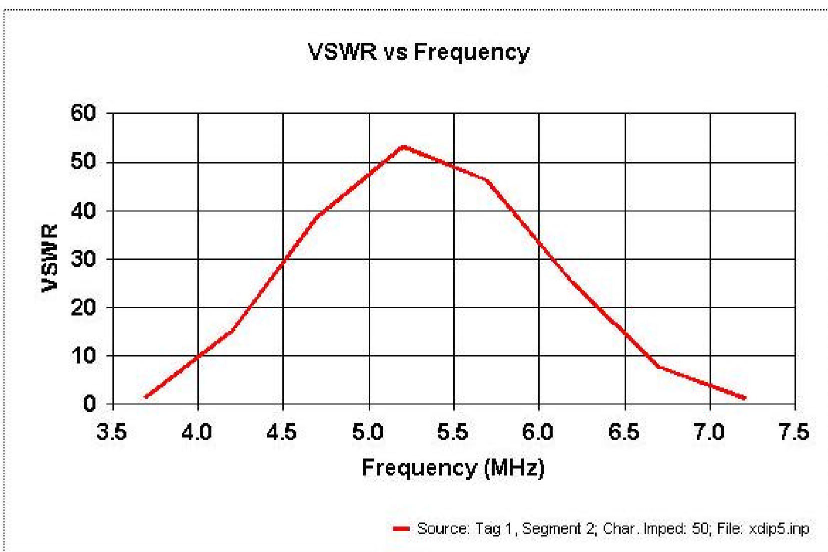


Figure 24. 40-80 Meter Crossed Dipole – 5Feet Above Ground –

Standing Wave Ratio

Individual frequency sweeps for the 40 and 80 meter center points showed that these antennas had individual SWR predictions of less than 2 SWR units.

The azimuth figures for the crossed dipole at the 3 heights follow:

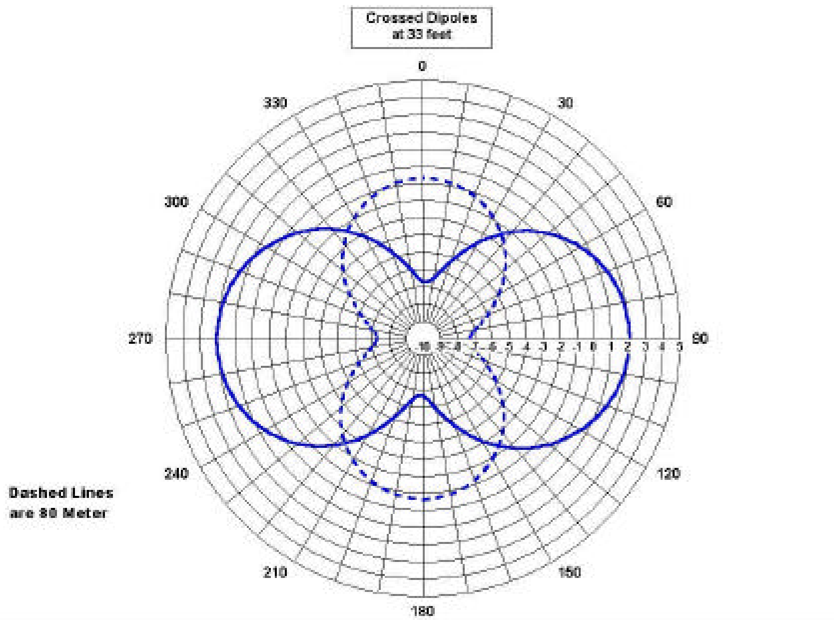


Figure 25. 40-80 Meter Crossed Dipole – 33 Feet Above Ground – Azimuth

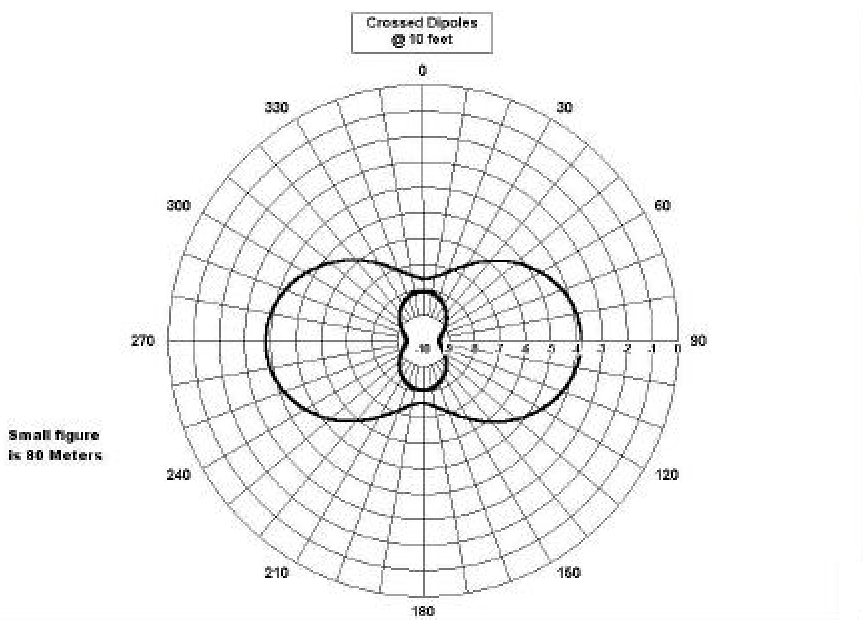


Figure 26. 40-80 Meter Crossed Dipole – 10 Feet Above Ground – Azimuth

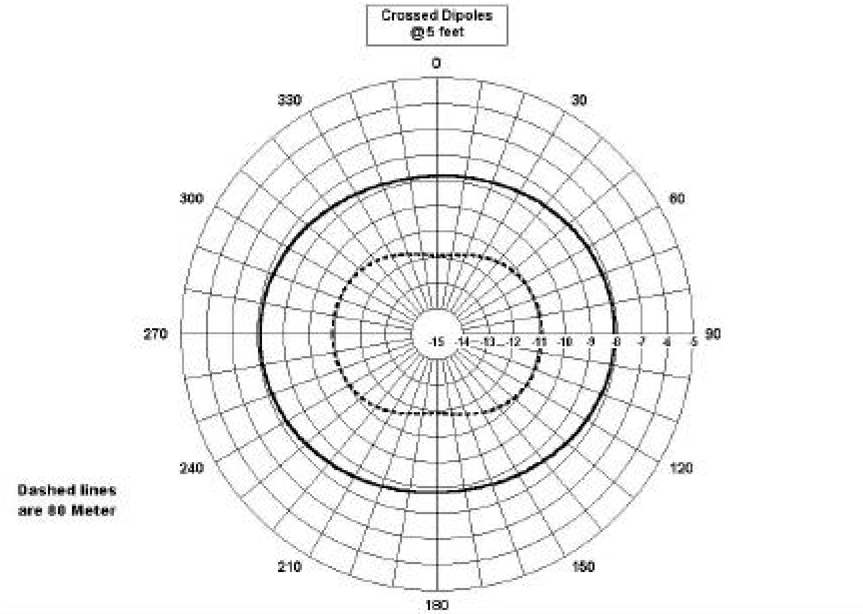


Figure 27. 40-80 Meter Crossed Dipole – 5 Feet Above Ground – Azimuth

Figs. 25 –27 show the dual band azimuth patterns of the crossed dipole configuration at all three design heights. Just as with the single band version, the amount of grazing angle radiation decreases greatly for the lower antennas.

For the elevation figures, calculation and graphing was accomplished on each of the major dimensions of the antenna. Because the antennas are crossed, each has a set of two elevation plots.

In Figs. 28 – 33, the elevation pattern for each antenna is shown on each of the primary axes, of the antenna pattern. As might be expected, the 40 meter patterns are very similar to what was seen in the previous work. The 80 meter patterns are not as efficient as the antenna gets closer to the ground.

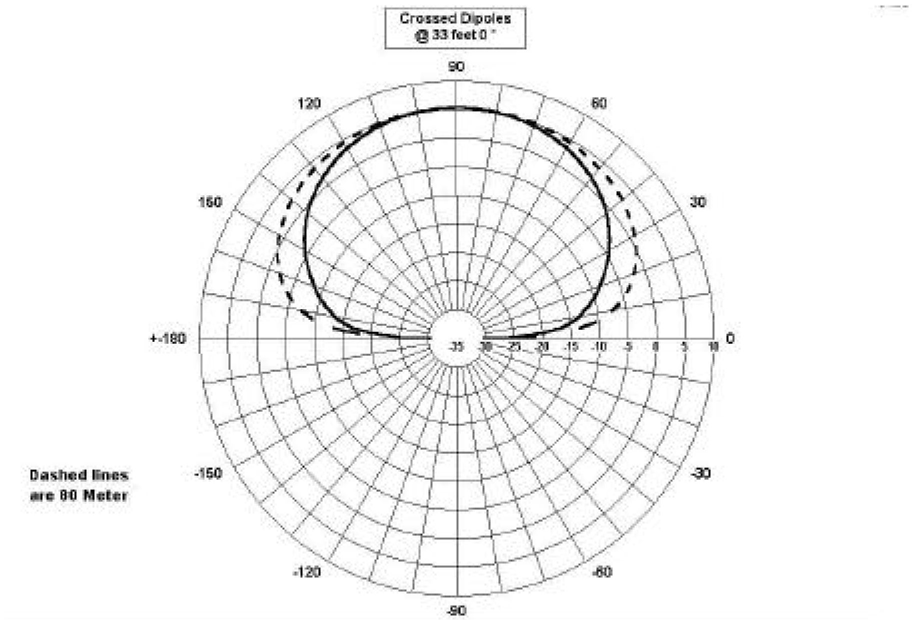


Figure 28. 40-80 Meter Crossed Dipole – 33 Feet – Elevation at 0 degrees Azimuth

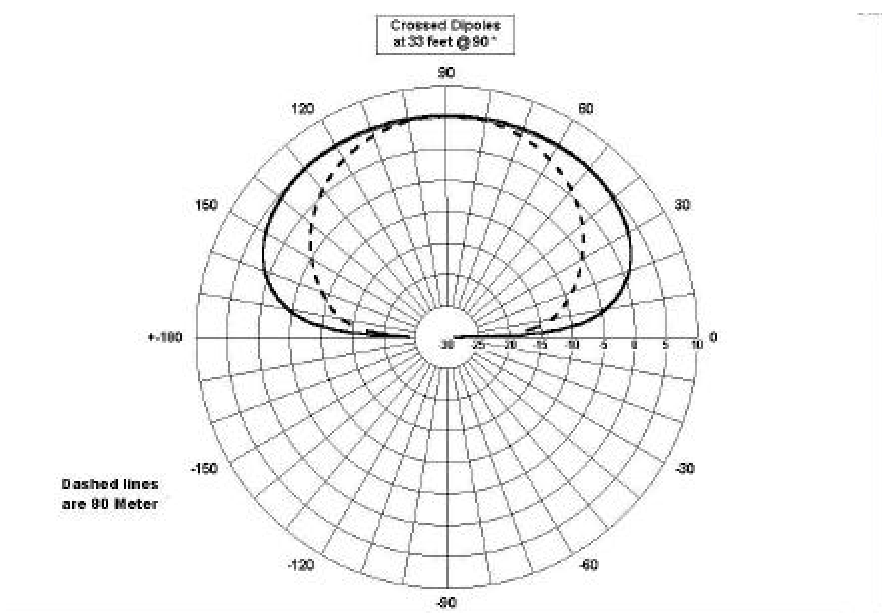


Figure 29. 40-80 Meter Crossed Dipole – 33 Feet – Elevation at 90 degrees Azimuth

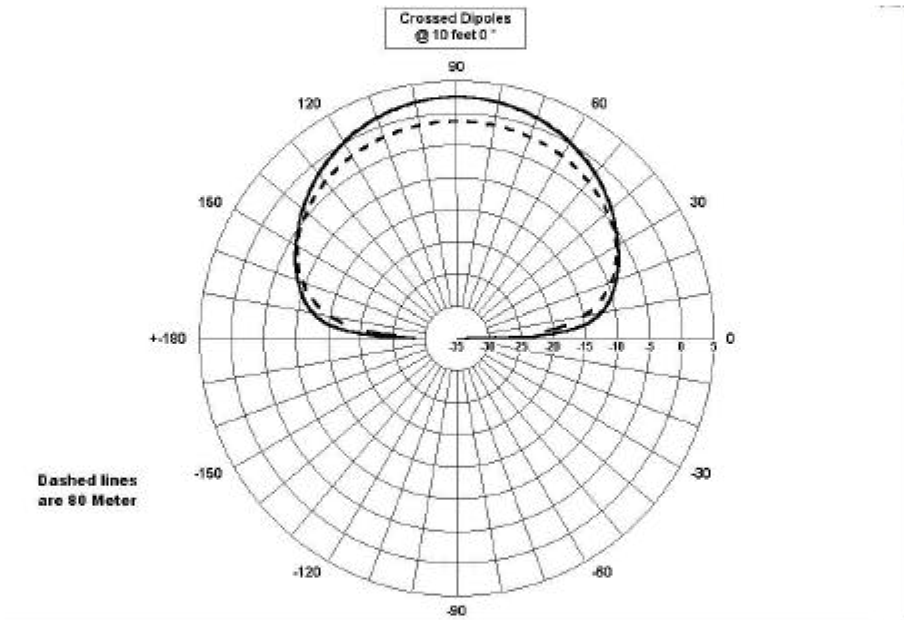


Figure 30. 40-80 Meter Crossed Dipole – 10 Feet – Elevation at 0 degrees Azimuth

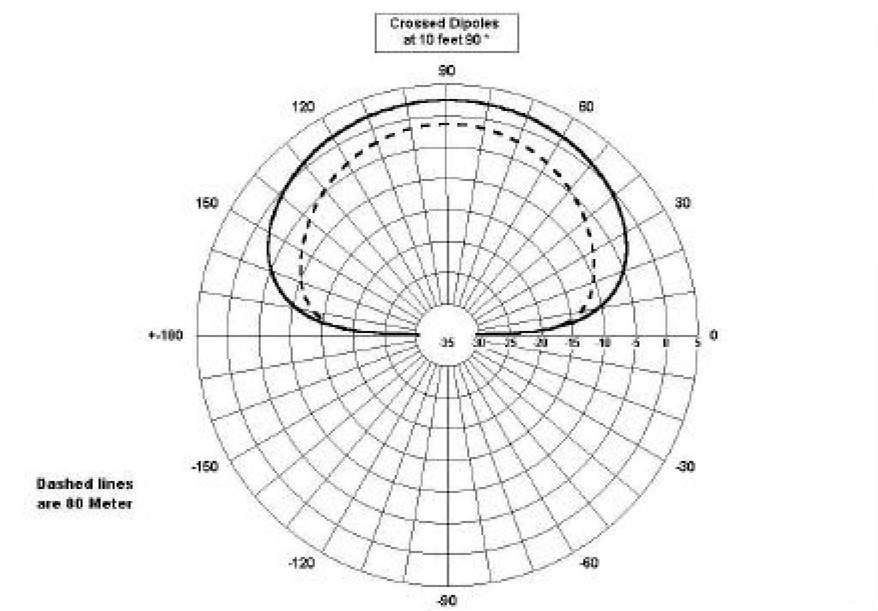


Figure 31. 40-80 Meter Crossed Dipole – 10 Feet – Elevation at 90 degrees Azimuth

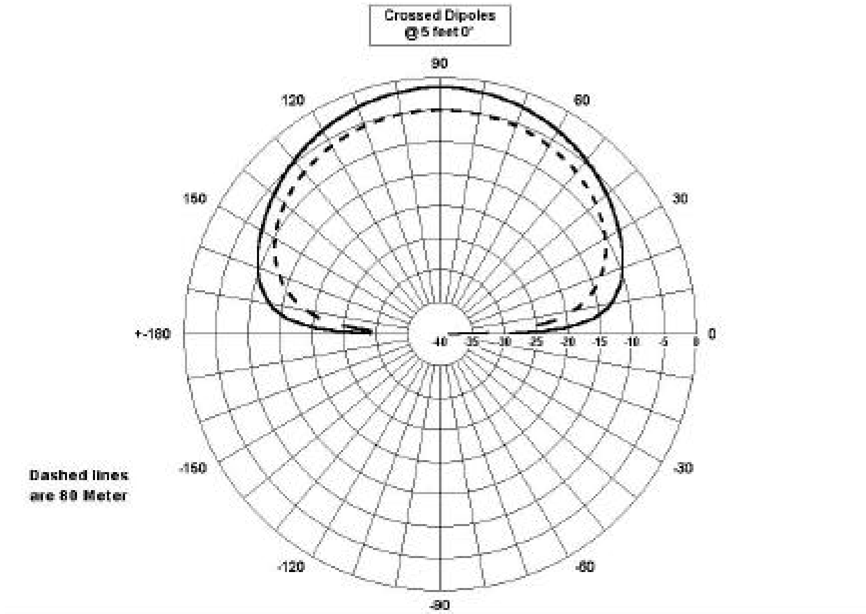


Figure 32. 40-80 Meter Crossed Dipole – 5 Feet – Elevation at 0 degrees Azimuth

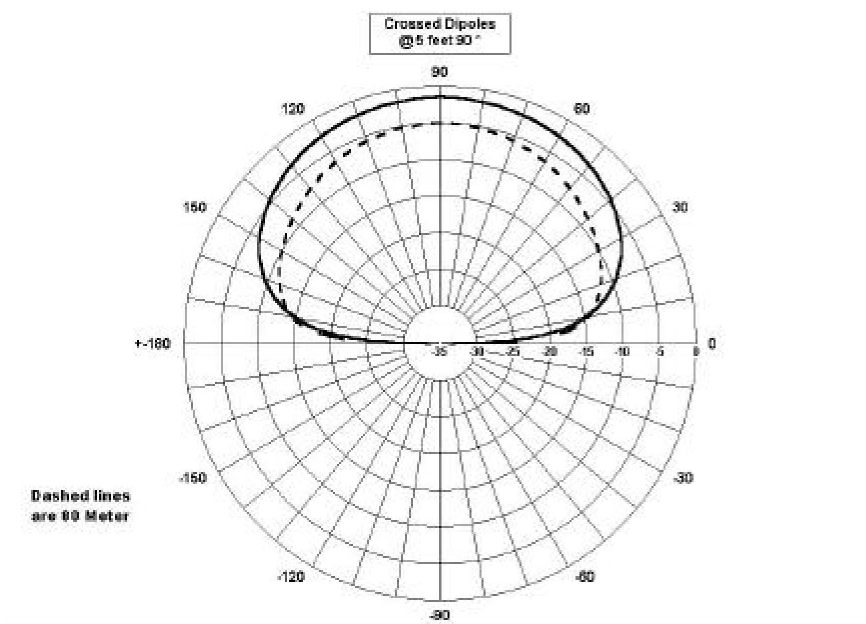


Figure 33. 40-80 Meter Crossed Dipole – 5 Feet – Elevation at 90 degrees Azimuth

Finally, the same comparison was made for two loop antennas. Several configurations are possible. Using minimal landscape, one of the most efficient designs is a corner fed pair of loops with the smaller loop sharing a part of two of the larger loop's sides.

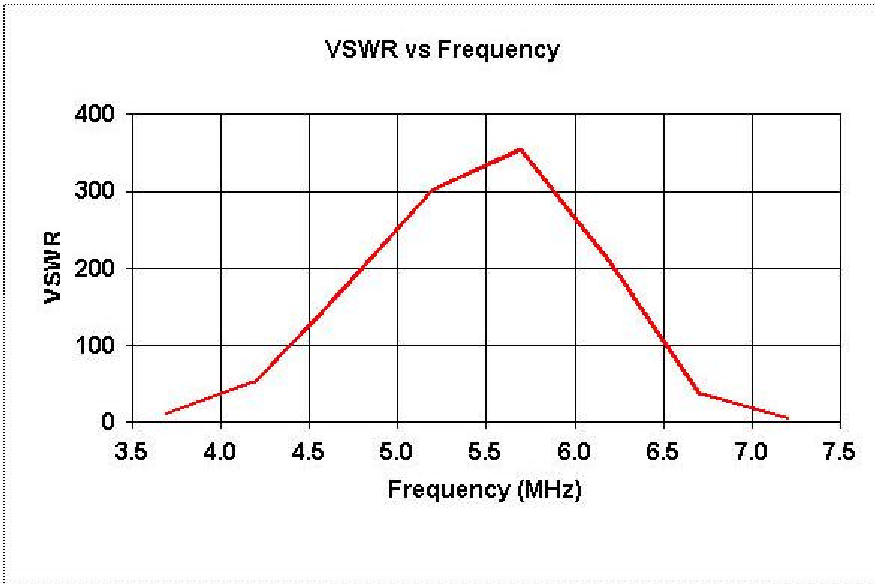


Figure 34. 40-80 Meter Loops – 33 Feet Above Ground – Standing Wave Ratio

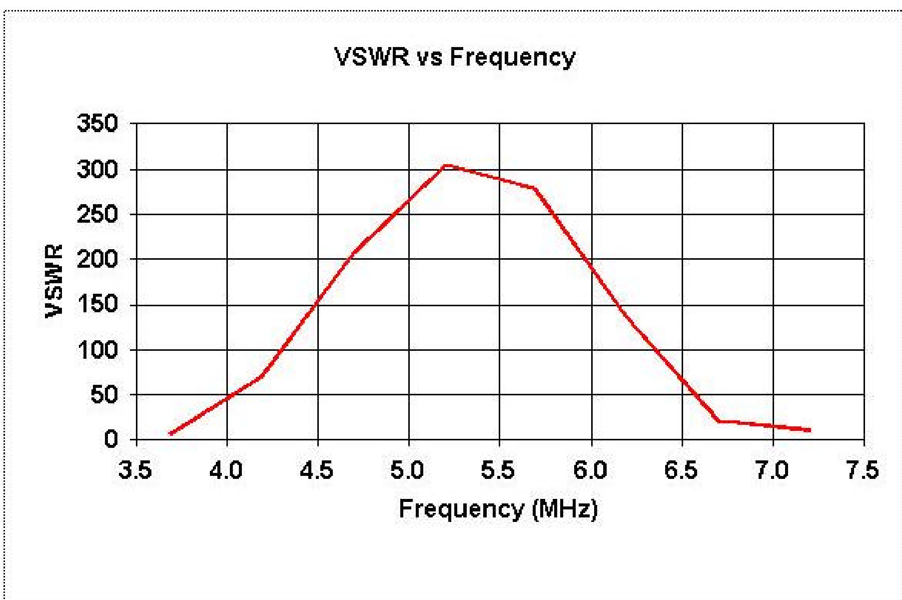


Figure 35. 40-80 Meter Loops – 10Feet Above Ground – Standing Wave Ratio

Figures of the antenna configurations can be examined in Appendix D.

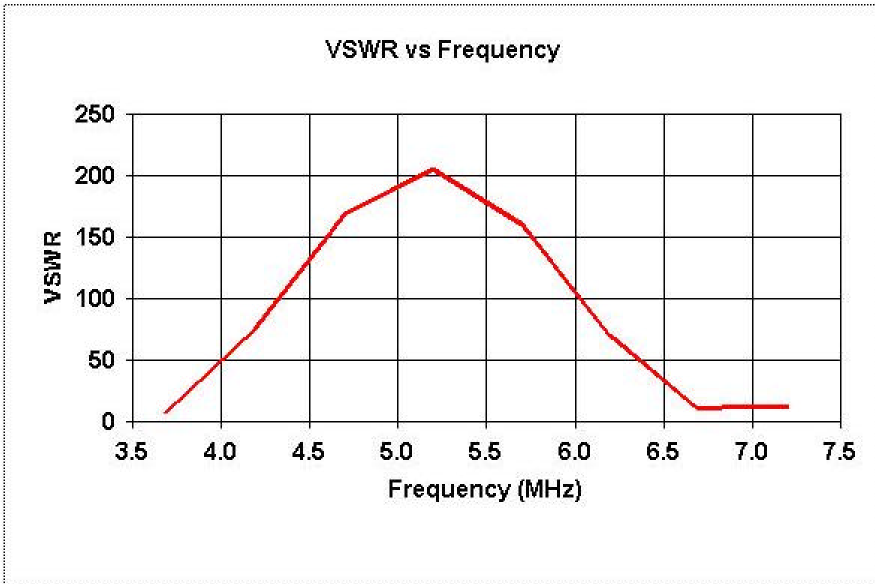


Figure 36. 40-80 Meter Loops – 5Feet Above Ground – Standing Wave Ratio

The Standing Wave Ratio of this system is seen for the three heights in Figs. 34 – 38. Unfortunately, it is very difficult to trim the double loop antennas for precise SWR on each band. For the 33-foot high antenna shown above, the detailed look at the resonant frequencies is shown in Fig. 37. The SWRs of 4 and 8 for 40-meters and 80-meters respectively, are for best achievable SWR and point out the large amount of energy that would be lost in the transmission line if a 50 ohm line were used.

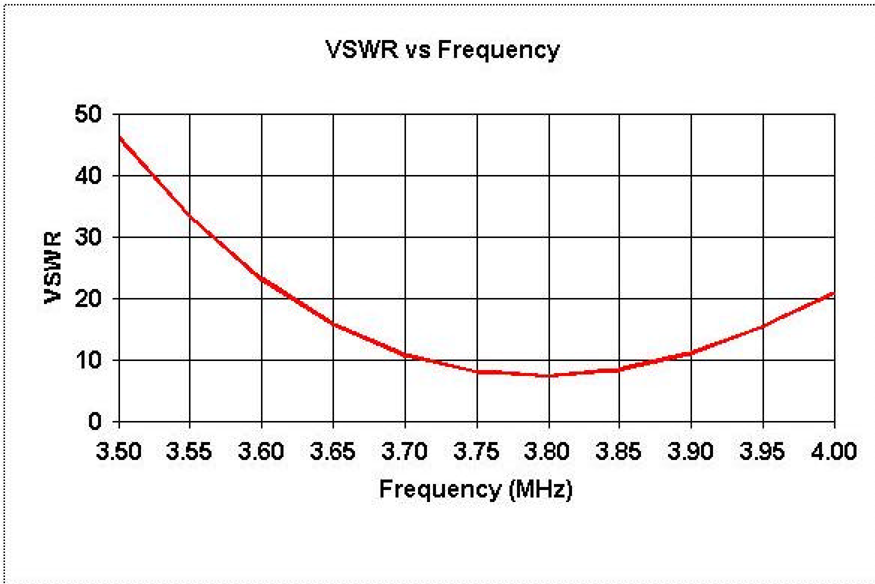


Figure 37. Double Loops – 33 Feet Above Ground – Standing Wave Ratio – 80 M

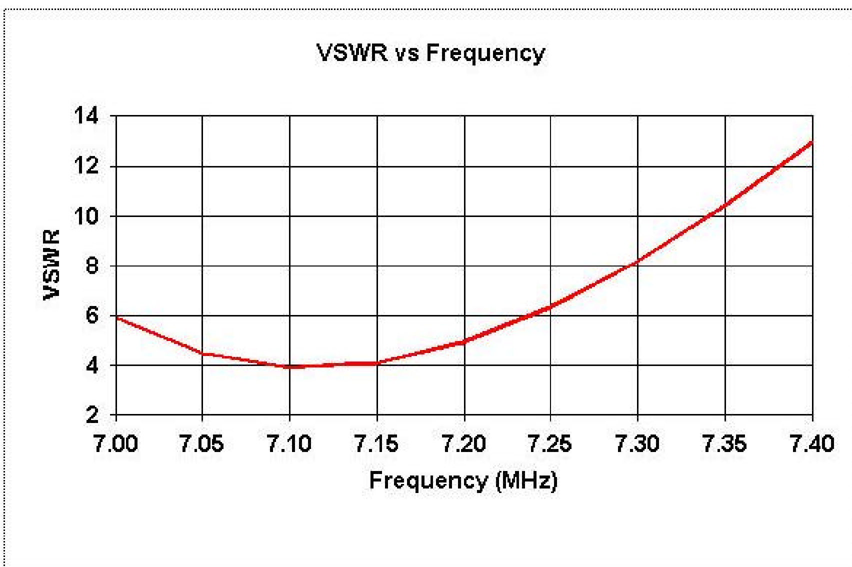


Figure 38. Double Loops – 33 Feet Above Ground – Standing Wave Ratio – 40 M

The Azimuth patterns are:

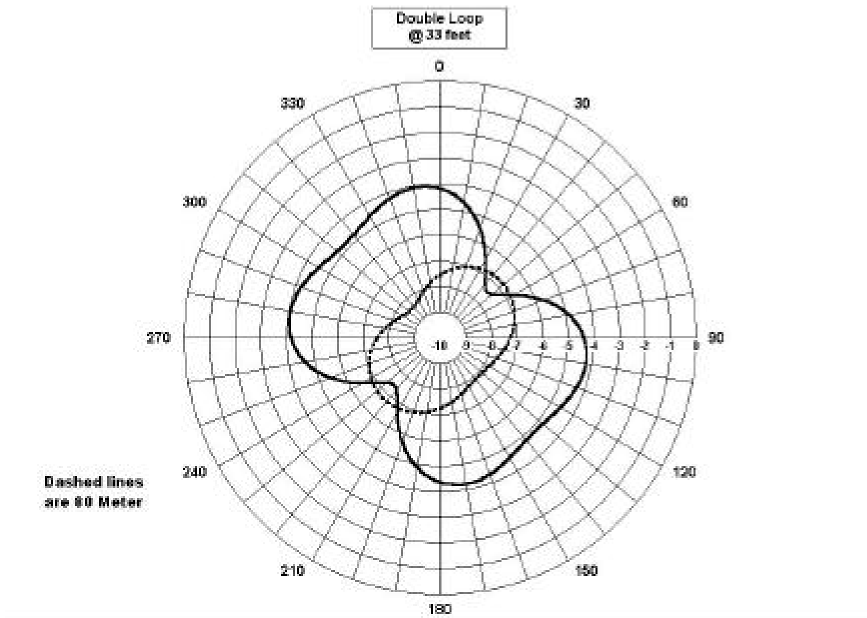


Figure 39. Double Loop – 33 Feet Above Ground – Azimuth

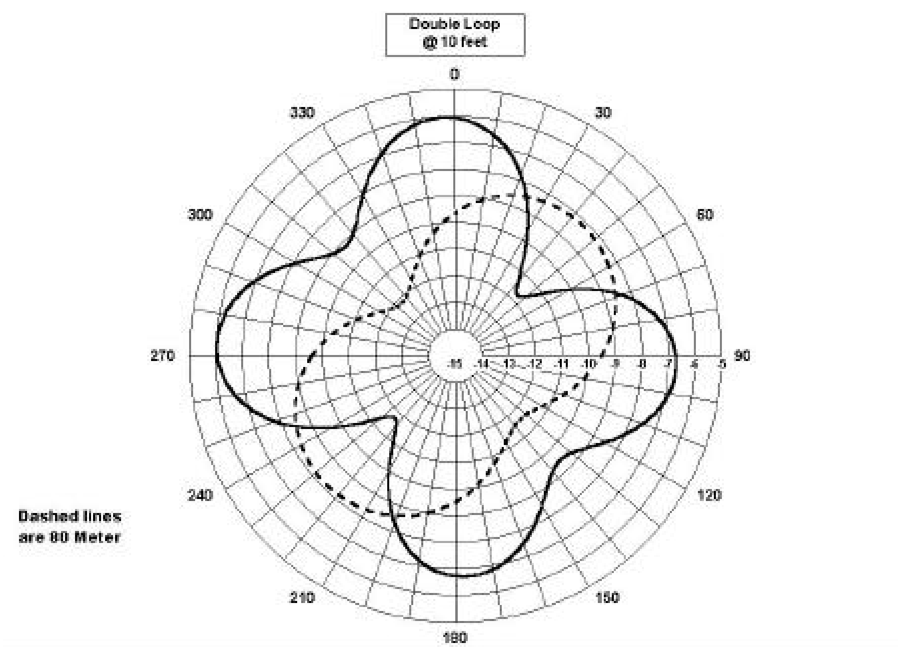


Figure 40. Double Loop – 10 Feet Above Ground – Azimuth

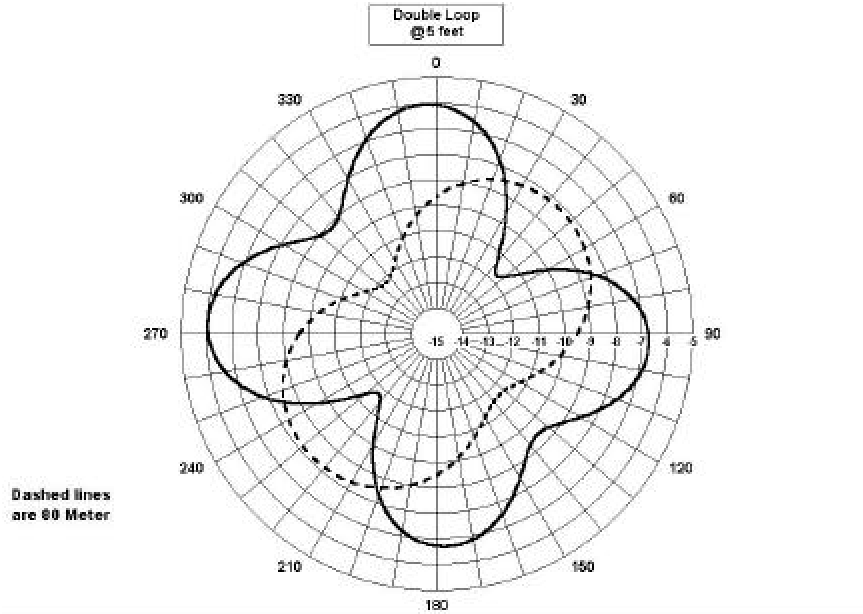


Figure 41. Double Loop – 5 Feet Above Ground – Azimuth

Figures 39 –41 depict the dual band azimuth patterns of the double loop antennas at the 3 heights. The 40 meter portions of these patterns are distorted by the presence of half wavelength antenna components in plane with the 40 meter quarter wavelength components.

And finally the elevation patterns are shown in Figs. 42 –47. As with the crossed dipoles, these antenna elevations are analyzed in each of the two major vertical planes of radiation. For each antenna, because the load is applied to the corner, two elevations are shown, one at 135 degrees of azimuth and the other at 225 degrees of azimuth. It may not be surprising, with the half wavelength components at the shorter wavelength, that the pattern has been distorted so that less energy is available for vertical transmission on 40 meters as there is available on 80 meters.

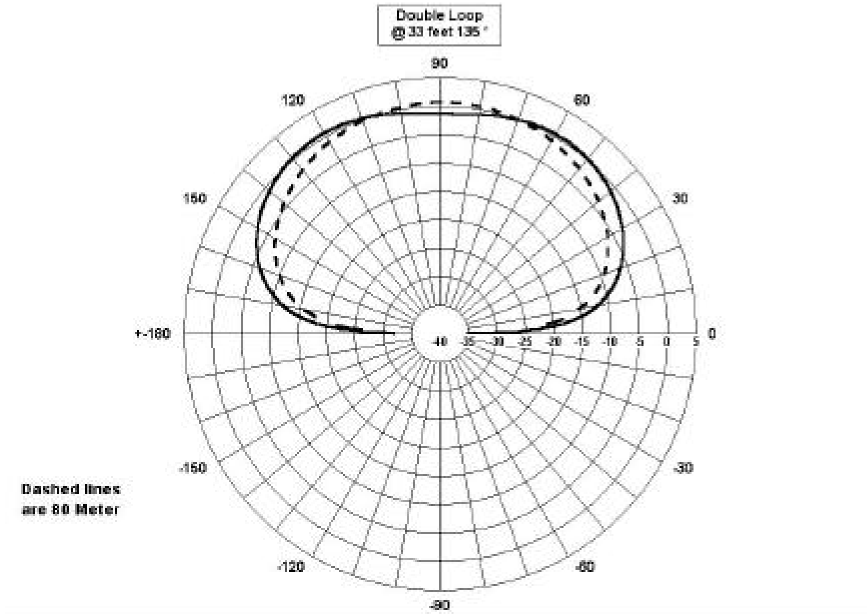


Figure 42. Double Loop – 33 Feet High – Elevation at 135 degrees Azimuth

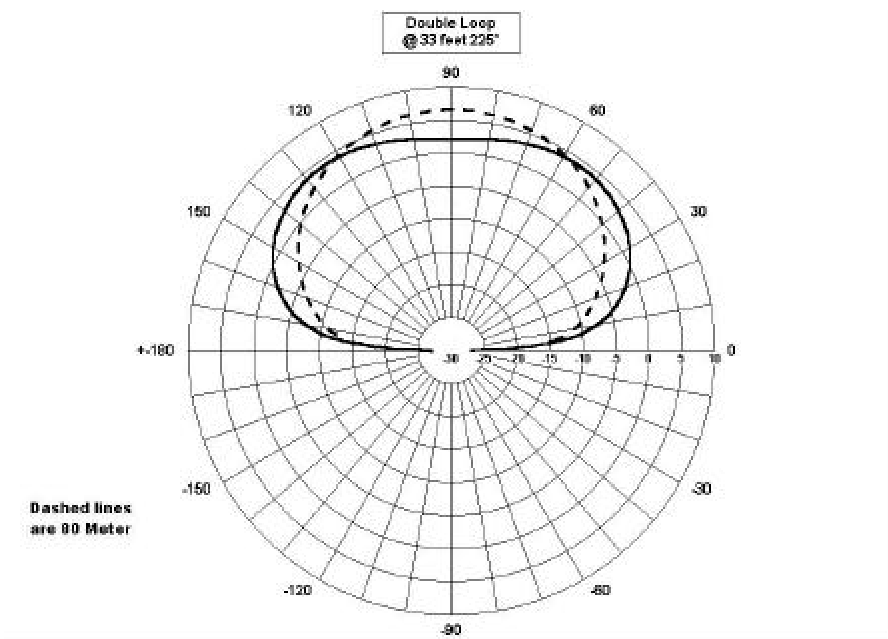


Figure 43. Double Loop – 33 Feet High – Elevation at 225 degrees Azimuth

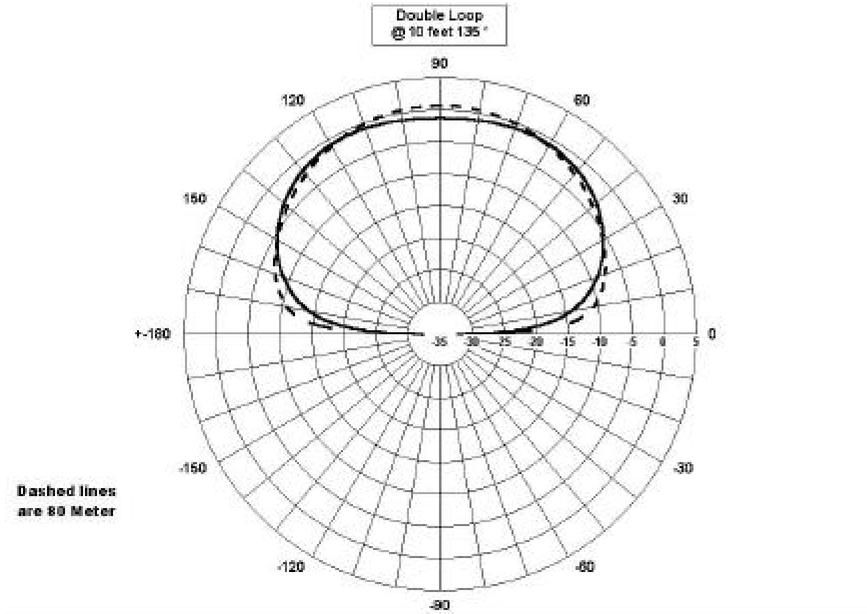


Figure 44. Double Loop – 10 Feet High – Elevation at 135 degrees Azimuth

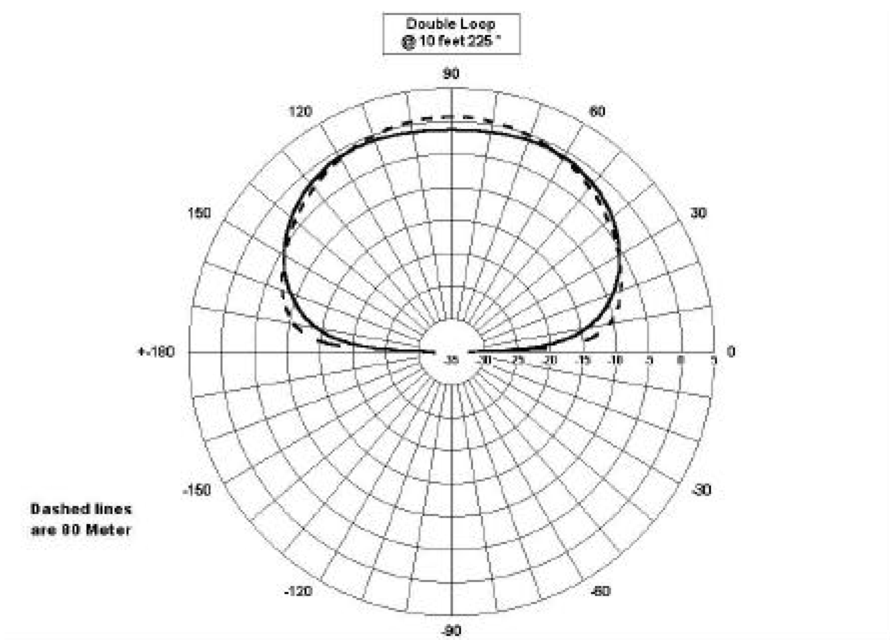


Figure 45. Double Loop – 10 Feet High – Elevation at 225 degrees Azimuth

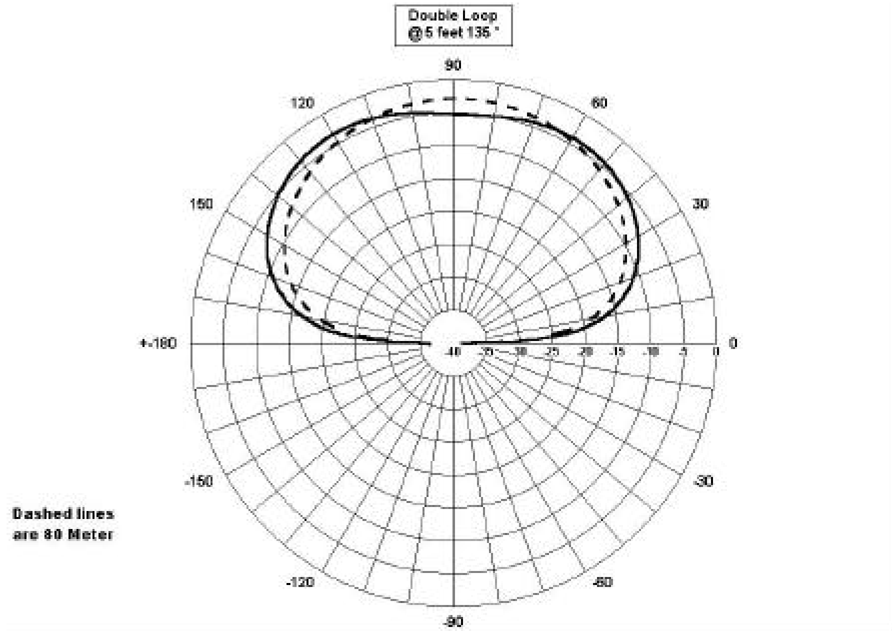


Figure 46. Double Loop – 5 Feet High – Elevation at 135 degrees Azimuth

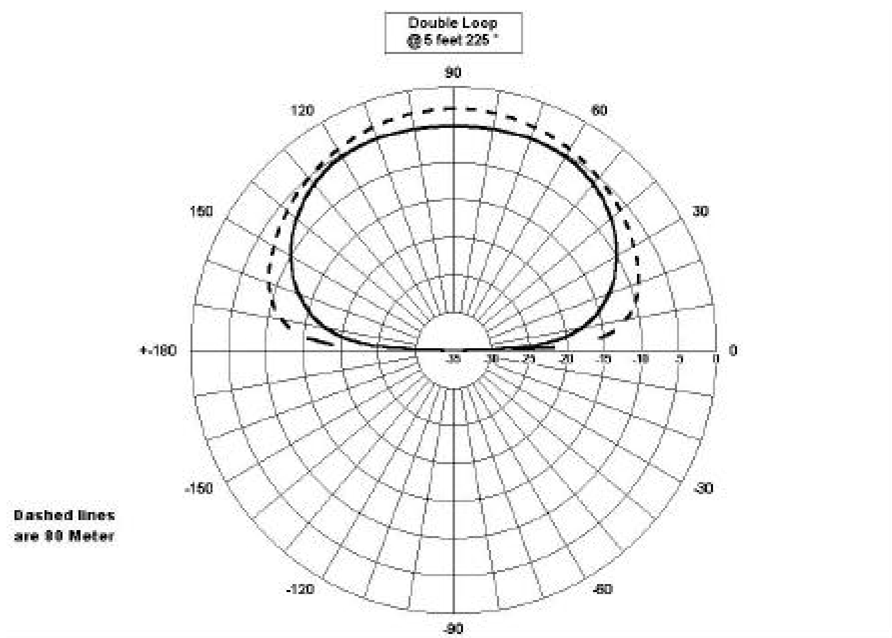


Figure 47. Double Loop – 5 Feet High – Elevation at 225 degrees Azimuth

The pattern of the loop antennas is somewhat distorted in elevation and azimuth for this system. While the main lobe of the antenna actually transmits more efficiently than the crossed dipole near the earth, the inability to closely match SWR drives down the performance of the antenna.

For completeness, a fourth antenna was briefly considered. Passive array antennas are frequently used as directional antennas in azimuth. A classic antenna using this principle is the Yagi antenna. With its reflector and directors, considerable gain can be realized.

Unfortunately, all these designs require a reflector at something close to a quarter wavelength behind a driven element to be efficient[6]. As has been seen in the forgoing, this is going to be a very high antenna even for the 40-meter band. This exposes the antenna to much more ground wave propagation which can have destructive interference.

Modeling for only the 10 foot height for the 40 Meter loop and dipole was accomplished to examine whether these antennas would have any significant advantage over their single element counterparts.

Figs. 48 –51 show the azimuth and elevation antenna patterns for a 10 foot high antenna with a reflector (of 10 percent increased dimension) on the ground. Comparision of these patterns with the corresponding patterns for the versions without reflector, show no significant difference.

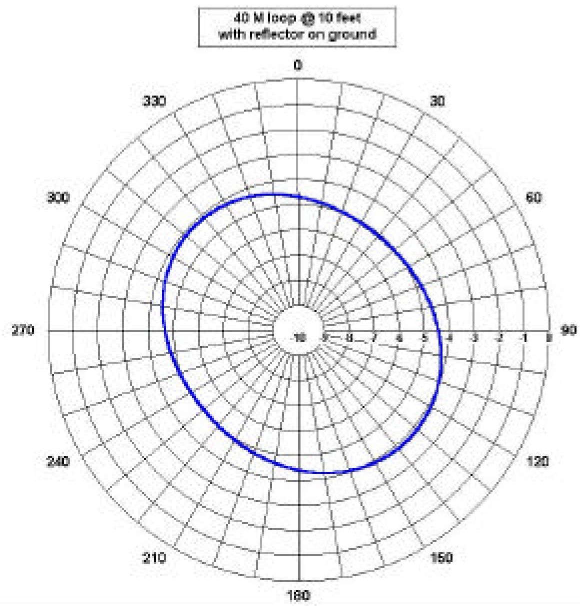


Figure 48. 40 Meter Loop at 10 feet with Reflector – Azimuth

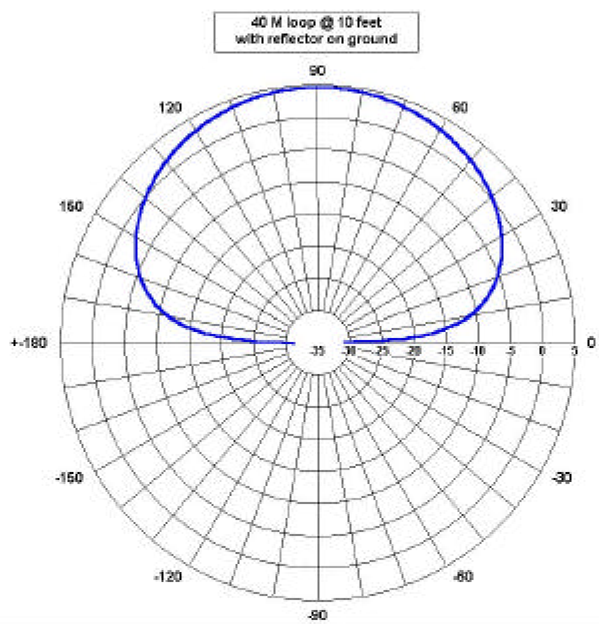


Figure 49. 40 Meter Loop at 10 feet with Reflector – Elevation

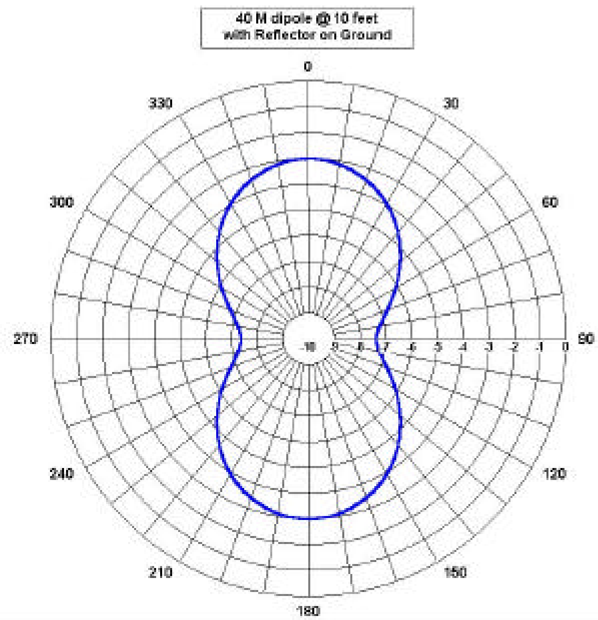


Figure 50. 40 Meter Dipole at 10 feet with Reflector – Azimuth

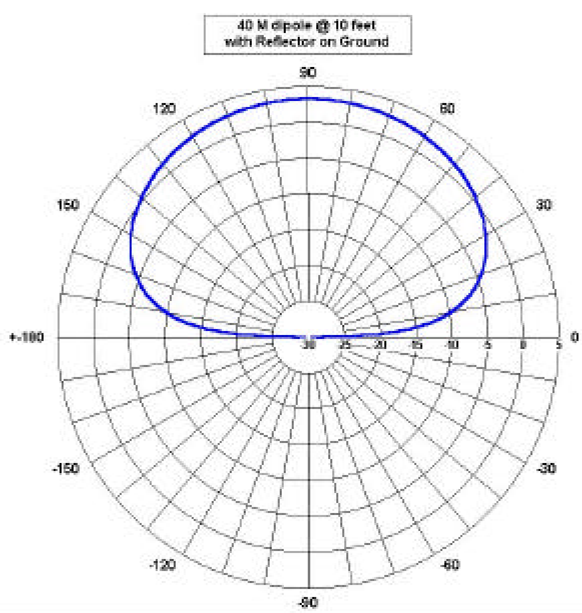


Figure 51. 40 Meter Dipole at 10 feet with Reflector – Elevation

Description of Quantifiable Digital and Analog Communication Techniques

Part of the challenge of these experiments was the comparison of digital communication techniques with analog voice techniques in a way that would be meaningful to operational and emergency personnel.

A number of techniques can be used to compare digital communications systems. The classic comparison would be the bit error rate [32].

The probability of bit error, P_B for coherent BPSK is:

$$P_B = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

where E_b is the energy per bit, N_0 is the noise energy, and where Q is given by

$$Q(x) = \frac{1}{\sqrt{2p}}\int_x^{\infty}\exp\left(\frac{-u^2}{2}\right)du$$

which is the complimentary error function.

The probability of symbol error, P_E, for M-ary MFSK is bounded by:

$$P_E(M) \le (M-1)Q(\sqrt{\frac{E_S}{N_0}})$$

where $E_S = E_B(\log_2 M)$, the energy per symbol, M is then number of symbols, and K is the smallest integer which fulfills: $M = 2^K$.

In these communications, the output was a series of characters on a screen. The characters were a product of several bits, and the bit errors rolled up into character errors in a not always predictable manner.

Even with ASCII characters, each of which is coded by a fixed length bit sequence, character errors do not necessarily relate directly to bit errors. Because of the random nature of bit errors, it is possible to have more than one bit error in a character error. It is also possible to have a bit error in a character and not have a character error – not all bit errors result in character errors.

All of this is considerably complicated by the actual character representations used by the COTS programs used in the experiment. Each program uses a similar (but not identical) "varicode" to encode each character. The marker at the end of a character is fixed as a multiple 0 bit with all the other characters not including the multiple 0 in their bit string. This allows the determination of a bit string terminator and variable length characters. Both systems assign common characters to the shortest bit representations, while less common characters are given longer representations [19, 25].

For all these reasons, and for the simplicity of describing the results to emergency radio operators, analysis is limited to character errors.

There were two digital methods used. The first was a simple binary phase shift keying (BPSK) system designed to occupy minimum bandwidth for a communication rate which would allow manual typing of messages between radio operators in a "chat style" communication link. It was assumed that operators would not type any faster than about 50 words per minute [25]. Words averaged 6 characters, and characters averaged 6 bits. The system transmits a bit rate of about 30 bits per second, given by

$$\frac{50_{wpm}\left(6_{ch/word}\right)6_{bits/ch}}{60_{\sec/\min}} = 30_{bits/\sec}$$

.

Applying standard digital techniques, since the system uses single side band transmission, W_{SSB} is the bandwidth of single side band required at radio frequency

$$W_{SSB} = \frac{1}{2}(1+r)R_S$$

where R_S is the symbol rate in symbols per second, and r is the roll off rate of the digital filter, here assumed to be 1. This means an additional 100 percent of bandwidth, beyond that predicted by the Nyquist sampling theorem to account for roll off, and

$$W_{SSB} = 30Hz$$

which agrees very well with the advertised bandwidth of 31 Hz in PSK31.

The second digital technique uses 16-ary frequency shift keying (FSK) with convolutional encoding, and interleaving used as forward error correction (FEC) techniques. Together, these methods are effective in dealing with the fading, static crashes, and interference that can occur on HF frequencies [19].

Knowing that the bit rate is doubled for FEC, the bit rate is given by

$$\frac{50_{wpm}\left(6_{ch/word}\right)6_{bits/ch}}{60_{\sec/\min}} = 30_{bits/\sec}\left(2\right) = 60_{bits/\sec} = R_b$$

and the symbol rate is given by

$$R_S = \frac{R_b}{K} = \frac{60}{4} = 15_{S/\sec}$$

.

The bandwidth can be calculated in the 16-ary case from the symbol rate. In an uncorrelated MFSK signal, the bandwidth BW_{FSK} is given by

$$BW_{FSK} \approx (M+1)R_S = 17(15) = 255Hz$$

where

K is the smallest integer which fulfils $M \leq 2^K$ and

R_S is the symbol rate in symbols per second.

Determination of expected error rates is complex for convolutional encoding alone. The COTS system used here was designed with a data bit rate twice that required for non-FEC communication. The bandwidth is nearly 10 times as wide as the BPSK bandwidth, at about 250 Hz [19]. Both signals are narrow when compared with an analog signal that utilizes a bandwidth of about 2000 Hz [34]. Trained operators can often recognize the information in signals with center frequencies as close as 1000 Hz, ignoring the low or high pitched audio from the neighboring single side band signals [30].

In looking for a quantified test of the quality of an audio communication signal, use was made of the clinical tests used by aerospace medicine specialists in diagnosis of operationally relevant hearing loss in trained aviators. Within the Air Force medical instructions, are several tests that allow a flight surgeon to send a word with a standard voice and have the pilot on the other end of a communication link circle one of three similar words [31].

The results of this test vary from one test physician to another, but each examiner becomes familiar with the results they expect from pilots. These results are remarkably similar between normal hearing pilots and only differ in a significant way when the pilot is having trouble with his hearing.

Different physicians have slightly different results from the tests, as it is possible for the test giver to attempt to make the words very clear or to say them more as words in normal conversation. This is a known bias to the test, and is impossible to control to an exact extent unless recordings are used instead of human examiners [31].

Unfortunately, recordings do not make the sorts of very automatic corrections to prevailing radio conditions that trained operators make. This kind of correction leads to some analytic confusion, but much more accurately represents what human operators actually do in the field.

Both operators in these experiments agreed to not consciously over-pronounce words or repeat them unless it was clear that a word had not been sent. Never was a word repeated because it had not been understood the first time. For the few cases that the word was not clearly understood, the receiving operator made a best guess.

The words are chosen to sound alike, not to look alike. It comes as no surprise that the operators were able to choose the word correctly more often with the digital modes than with the analog single side band mode. It may also come as no surprise to the field operator that a more accurate message can be received by digital methods than by audio.

But using the digital modes with these word lists and by comparison with the actual transcript from the two sites digital communications was designed to not only find the number of character errors, but to compare the words answered correctly with the words that should have been able to be answered correctly from the transcript.

By knowing the number of words answered correctly, as compared with the number that should have been able to be answered correctly, some estimate of the number of word errors an operator makes due to human factors. Using this information, inference can be made about the true analog error rate as compared with the recorded analog error rate.

The word lists used in the experiment can be viewed in Appendix B.

Data Collection

The data was collected from December 2001 to January 2002. The solar cycle was beginning to wane, though conditions for HF propagation were still good. The previous peak had occurred about one year previous to these tests. The data were all collected with a set combination of antennas. The WS8B site was a sloping inverted V antenna. The WS8G antenna was a horizontal dipole at 5 feet above the natural ground.

All experiments were conducted on the 40 M amateur band. The analog portions of the tests were conducted at or near 7.16 MHz, and the digital portions were conducted at 7.065 MHz. These frequencies were chosen to comply with the established band plan for the amateur service.

The method selected for collection of data was for each operator to send three different 50-word tests. Each operator sent and received each of three modes. From each geographic site the mobile operator took, there is a set of 6 tests. Each test has approximately 215 characters.

Words were sent in blocks of 5 regardless of mode. The sending operator would wait for an acknowledgement from the receiving operator before continuing. Groups of words were not sent a second time, even when the operator knew they had difficulty with one of the words for any reason. Occasionally, when it was agreed by both operators that a word that should have been sent had not been sent at all, the word was sent on special request. This happened very occasionally in the analog mode with the first or last word of a group of 5.

During each test, the receiving operator filled in a multiple answer sheet. Three choices were available for each transmitted word, and the operator circled their best guess of the correct word. The sheets were labeled to show the date, operator, mode, frequency, and distance between stations. The sheets were collected and were the primary data source for parts of the analysis.

In addition, a character-by-character computer log was maintained on each operator's computer system during the digital portions of the testing. These logs were stored and later printed. They became the basis for character-by-character analysis of the digital data.

Several other data collection techniques, as follows, were considered and rejected. While other researchers may find these data techniques useful, their collection at this stage was not conclusively necessary.

An additional analog data source that was collected were audio recordings of the single side band data sessions. This information would have been valuable in the analyzing human error, by allowing a second trained operator to listen to the recorded source and attempt to select correct words.

Another analog data source could have been a video recording or digital storage of the sound card's spectral power waterfall display. From this display, the operator can observe the interplay of nearby signals and broadband noise sources. Together with an audio recording of the digital signal, a further impression can be gleaned for analysis. Unfortunately, no simple and expedient method to analyze or present this as anything more than anecdotal data was discovered.

Mobile Site Description

Data was collected from four separate geographic areas. These were chosen to represent several of the difficult field situations that exist in the relative close range. The usefulness of HF communications at great distance has been previously described in reasonable depth – as has the problem of skip propagation. The characteristics of VHF and UHF using LOS communication are also well described. These locations were chosen to represent places where UHF and VHF would be blocked and from which short-range HF contacts might be difficult.

The experiment was conducted with a fixed station and a mobile station. The fixed station, WS8B, whose antenna system was previously described, is attached to a suburban home. At an elevation of about 700 feet above sea level, it sits on what was once rolling farmland. The terrain is reasonably flat, and the station is in neither a valley nor on a high point with regard to the surrounding area. For a topographic map of the site with orientation of the antenna, see Fig. 52. Measured Global Positioning Satellite GPS coordinates match the coordinates on the topographic map and are available upon request from the author. All mobile sites were to the west of WS8B's location.

For all maps that follow, North is toward the top of the page, and the scale is 1:25000.

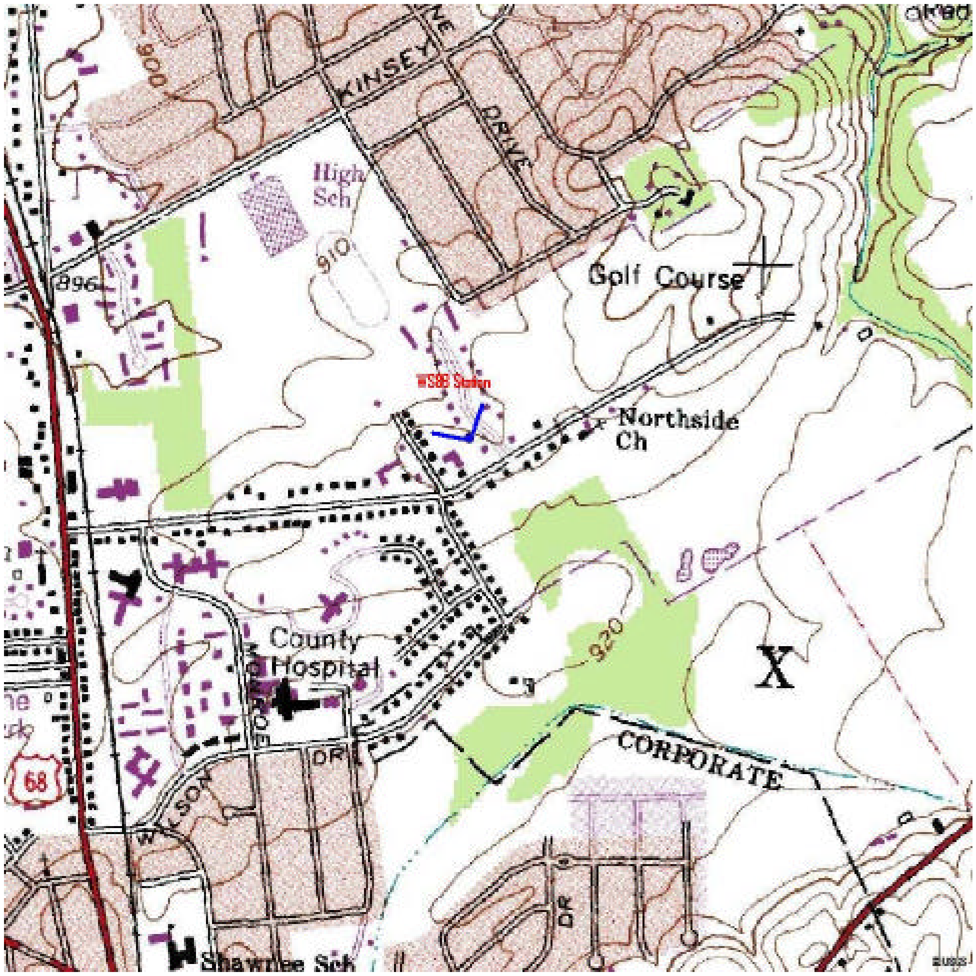


Figure 52. WS8B Station

The first mobile site (Fig. 53) was a flat grassy area near the home of WS8G. The site is about 600 feet above sea level, and is also situated on what was once rolling farmland. The site contains a number of trees, none of which were closer than a quarter wavelength from the antenna. The antenna was situated along a straight line measured from 70 degrees to 250 degrees azimuth. This site is about 6 miles west from the WS8B station. There are no intervening hills or obstructions of any extent, though visual line of sight cannot be achieved. Low power VHF communications were used during the tests from this location to coordinate final configuration of the radio and computer systems, confirming the presence of line of sight to 147 MHz communication.

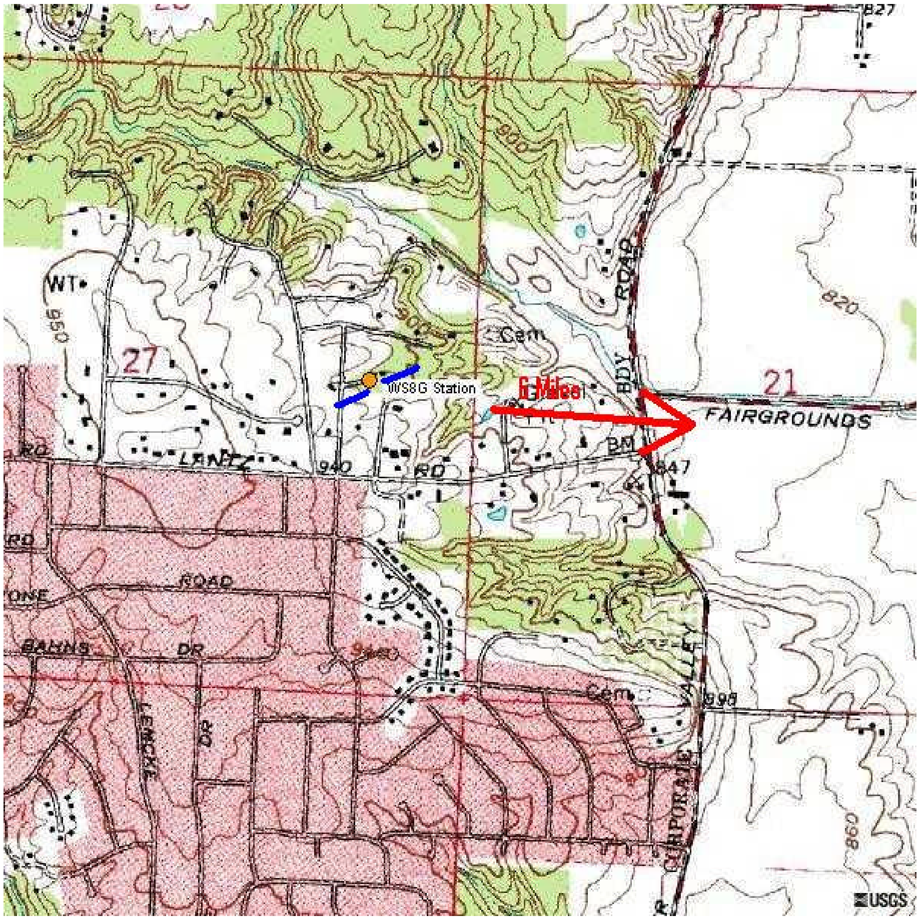


Figure 53. WS8G Home Station

The second mobile site, 23 miles west-northwest from the WS8B station, was chosen to present a very difficult terrain for line of sight and ground wave transmission. This spot (Fig. 54), in the Englewood Reserve, was situated in a 150-foot (verified by GPS measurement) deep valley with a very steep rocky and forested wall immediately east of the mobile position. The position of this wall was directly between the mobile station and the fixed WS8B station. Simplex communication between the stations on VHF could not be achieved. Repeater based communication using a high tower near the

WS8B position was also not possible. Even cell telephone communication was very difficult, though the station was within a few miles of Englewood, Ohio and Interstate 70. The antenna was sited nearly east and west, over a frozen grassy picnic area. Trees were present, but none were within a quarter wavelength of the antenna.

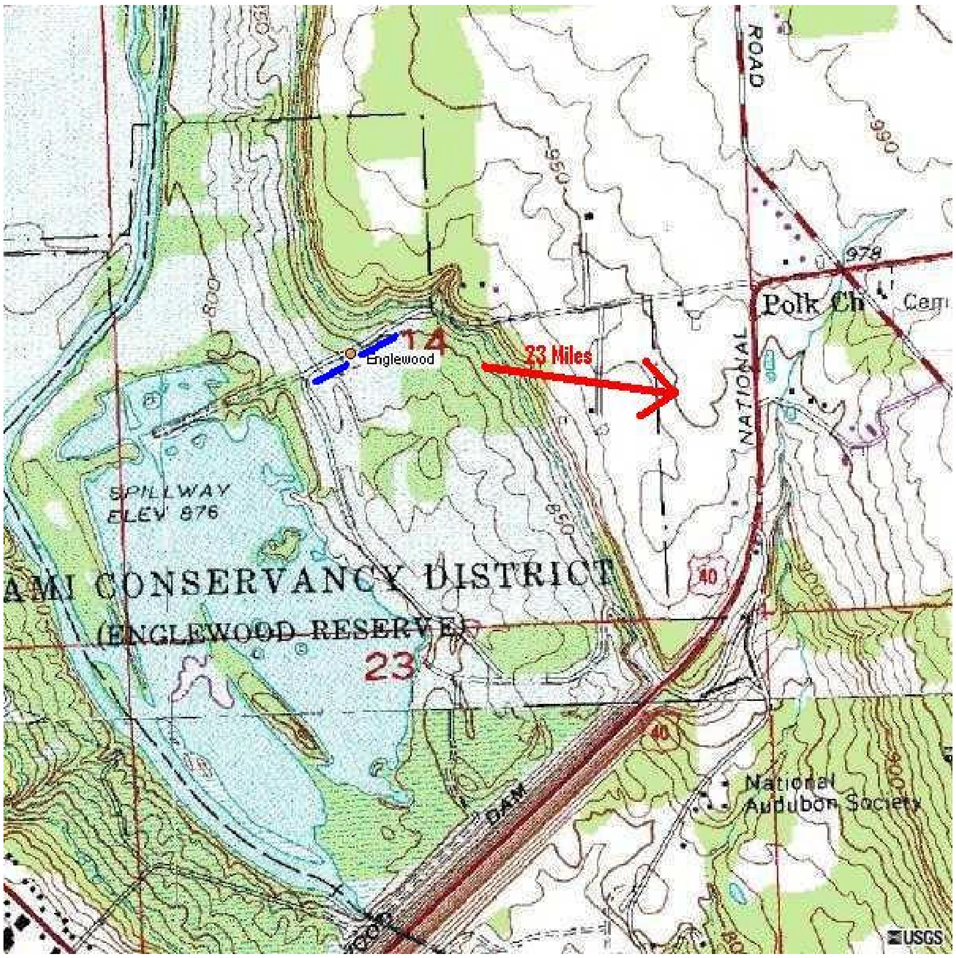


Figure 54. Englewood Reserve Station

The third mobile site, 46 miles west-south-west of the fixed WS8B station, was situated in a rolling valley; about a hundred feet lower than the surrounding countryside, near the lake in Hueston Woods State Park. This site is illustrated in Fig. 55. The antenna was sited along a 10-foot wide east-west strip of grass in a parking lot at the state park lodge.

Figure 55. Hueston Woods Station

The last mobile site (Figs. 56 - 57) was chosen to explore the sorts of difficulties urban canyons impose on line of sight communication. Though only 11 miles from the WS8B site, this spot, on a narrow grassy strip next to a large metal clad building, represents city streets surrounded by tall buildings - the urban canyon. This site is on the lower part of Wright Patterson AFB, about a hundred feet below the surrounding countryside, with a hillside between it and the WS8B station. The road and the hillside are perpendicular to a line connecting the stations.

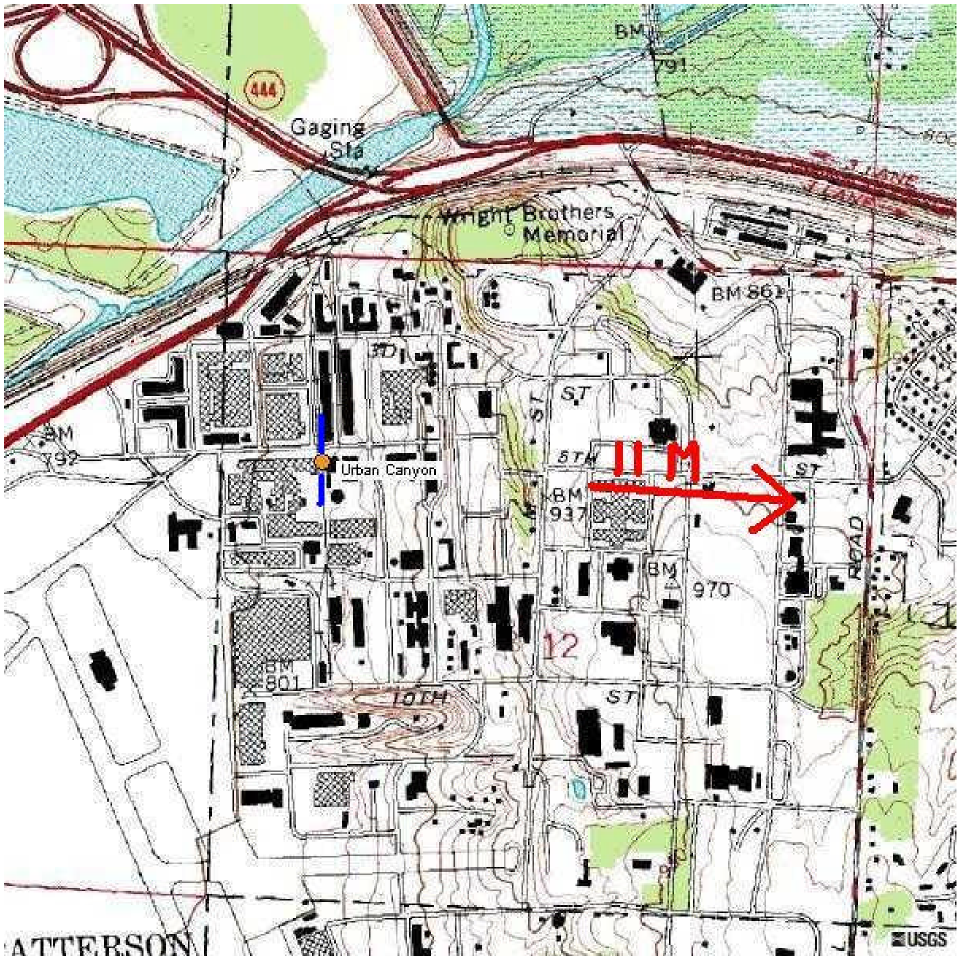


Figure 56. Wright-Patterson Station - Topographic

Radio conditions for most of the tests were about average on the HF bands with the exception of the testing from this urban canyon. A contest on the digital bands was in full swing when this testing was accomplished. There were a multitude of competing stations on the digital sub-bands.

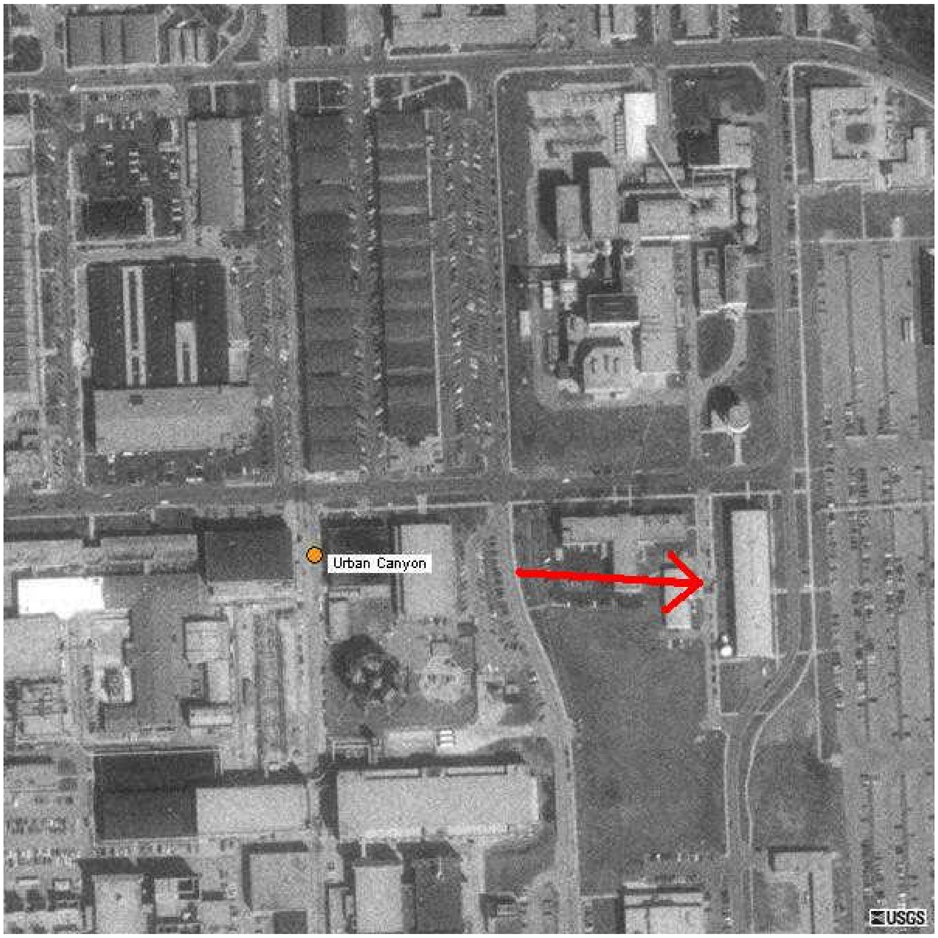


Figure 57. Wright-Patterson Station - Satellite Photo

Analysis Procedures

The data from the experiments was analyzed in two ways. Obviously, the answer sheets were graded, so that conclusions could be drawn from the errors. The digital data logs were also examined toward several ends.

For the answer sheets, the known list of sent words was used to correct the words the receiver believed they had heard. This analysis was not conducted in the field, and the operator had no feedback as to their success during the experiment. There was therefore no concurrent knowledge of how the radio operator was doing in comparison with their other tests or in comparison with the other operator.

Both operators had access to the correct words, but the lists were found to be far too long to attempt to memorize the word order. The operators had discussed data collection previous to the tests and had decided that the best way to answer the questions was to make a first choice and then stick with it. There was no evidence on the answer sheets of corrections to answers once chosen.

The digital data consists of eight ASCII streams, one from each operator for each time the mobile WS8G station moved. These streams include all the characters sent by the operator, and the decoded characters obtained from the program's analysis of the received waveform.

Within each stream, there are four lists of 50 words. Two lists are the characters sent by the operator and are assumed for these purposes to be an accurate account of the keyboard entries made by the operator. The other two lists are assumed to be the characters as they appeared to the receiving operator on their computer screen. The only discrepancy from this is the use of the back space key. The ASCII stream accurately shows all backspace entries made by the operators. The operator often did not see these backspaces or have time to process the information removed by the backspacing before it was replaced with new information.

The operators made a number of typing errors. In almost no case, did the typing error lead to a missed word on the answer sheet. All typing errors were compared from one computer's log to the other computer's log to determine the character error rate, regardless of whether an operator answered correctly on the answer sheet.

Of interest, in nearly every instance when a single character error was sent – a misspelled word – the receiving operator chose the correct word on the answer sheet. The same cannot be said for correctly spelled words. Of the words incorrectly answered on the sheet, a number of these errors were attributable to the operator reading the right word on the computer screen and then circling the wrong word on the answer sheet. To err is human.

Mathematically this can be expressed as follows:

$$E_{word} = (Ch_e - H_c) + H_e$$

where E_{word} is the total number of word errors, Ch_e is the number of words coming through the channel with an error, H_c is the number of words corrected by the operator, and H_e is the number of words recorded in error by the operator.

IV. Results

This work is a descriptive study with conclusions drawn from qualitative analysis of data collected. At one level, it describes the quantity of information that can be passed with NVIS communication techniques. From a human factors perspective, it examines the interaction of trained radio operators with technology.

Performance Testing

As seen in Fig. 58, the overall test performance for analog accuracy by both operators was 92 percent. Operator A's scores were consistently better than scores for operator B.

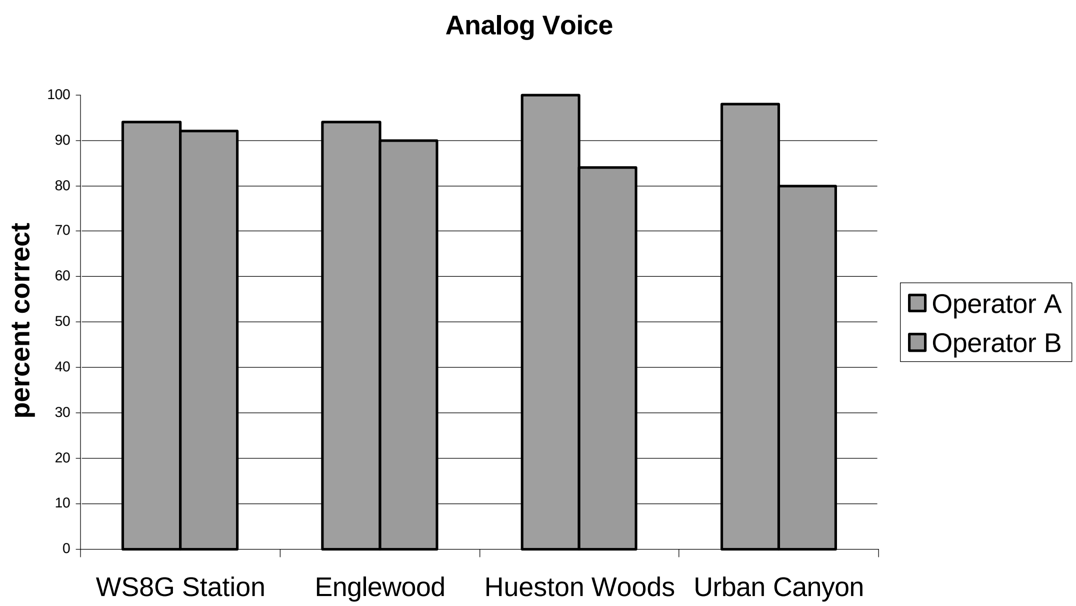


Figure 58. Voice Scores for Each Location - Operator A and B.

This could have been improved if the operators had used a standard phonetic alphabet to spell out each word as though it were a critical item of information. For example, phase would become “Poppa Hotel Alpha Sierra Echo.” This method was not separately examined for this work.

The overall test performance for Binary Phase Shift Keying (BPSK) was 98 percent. Fig. 59 shows BPSK performance was better than analog voice.

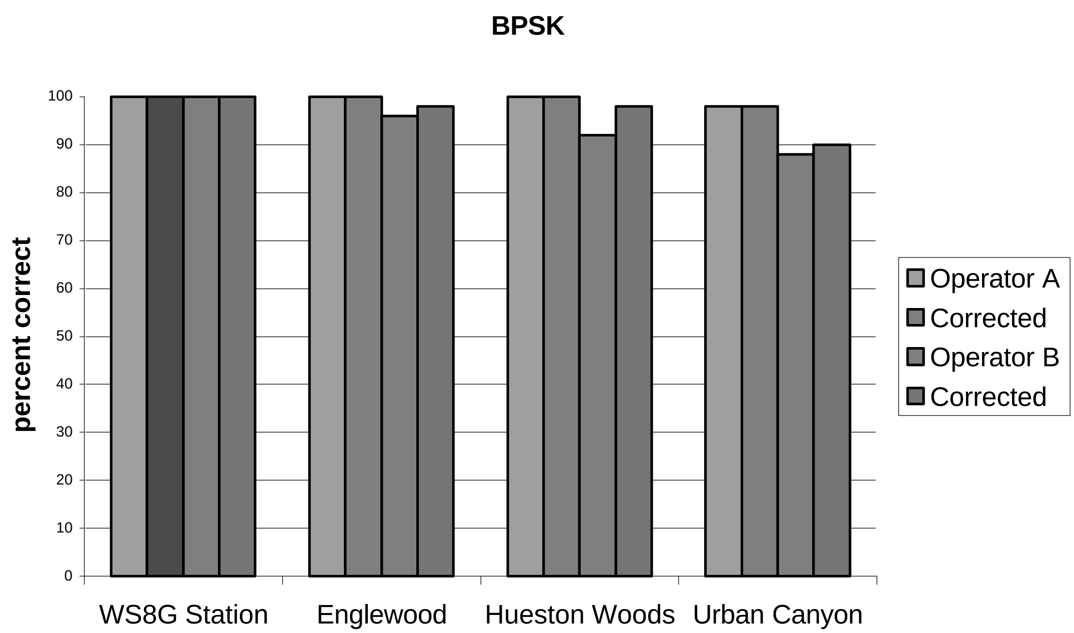


Figure 59. Percent of Words Correct for Each Location BPSK

The test performance for MFSK with convolutional encoding and interleaving seen in Fig. 60 was better than analog voice. Fig. 61 shows there was no consistent difference between the two digital modes except on one day when there was a higher level of interfering signals than on any of the other days.

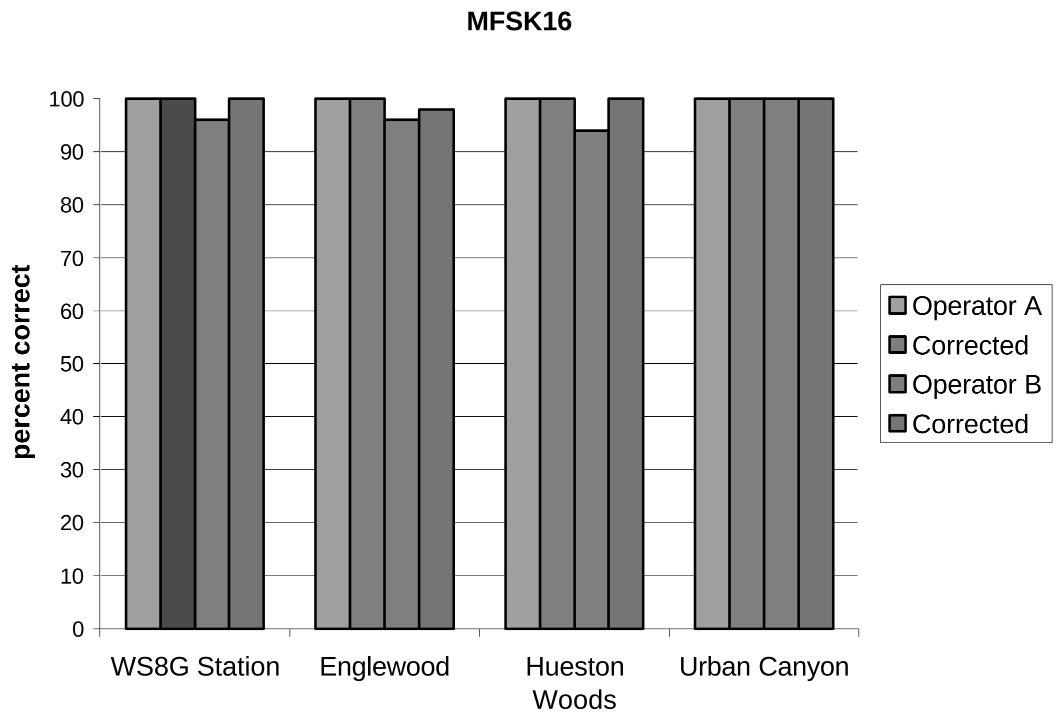


Figure 60. Percent of Words Correct for Each Location MFSK.

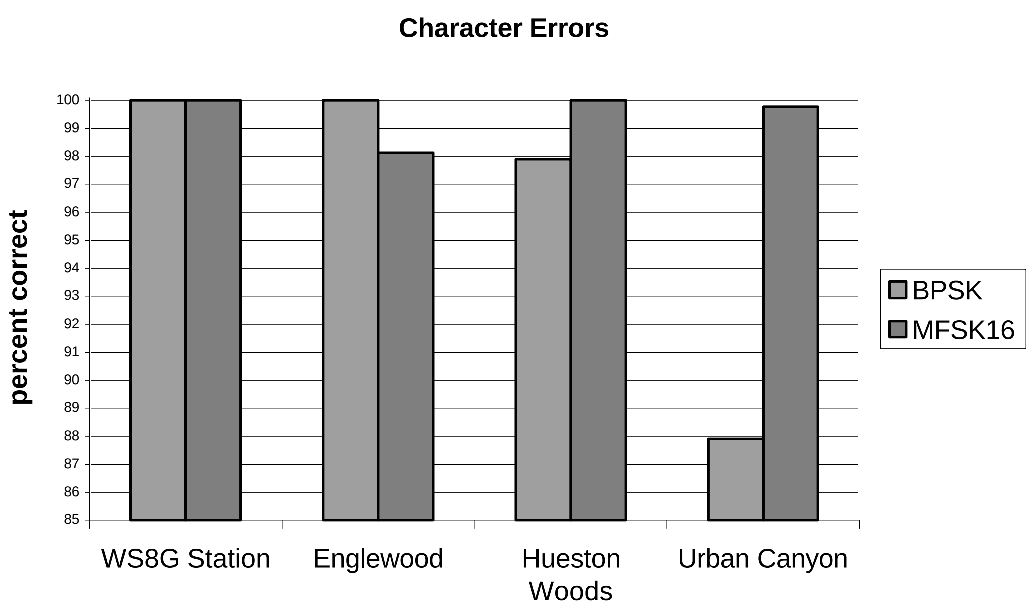


Figure 61. Percent Character Errors – BPSK and MFSK

The actual performance of the digital modes was better than the human recording of the digital modes. Both Figs. 59 and 60 show that if the operators had not made errors, the accuracy rate would have been better than the test performance indicates.

Based on this collected data, Fig. 62 demonstrates the clear differences between the error rates for the three modes. Examining the overall performance of the operators (without correction) for the three modes, it is clear that the digital modes did better than the analog voice.

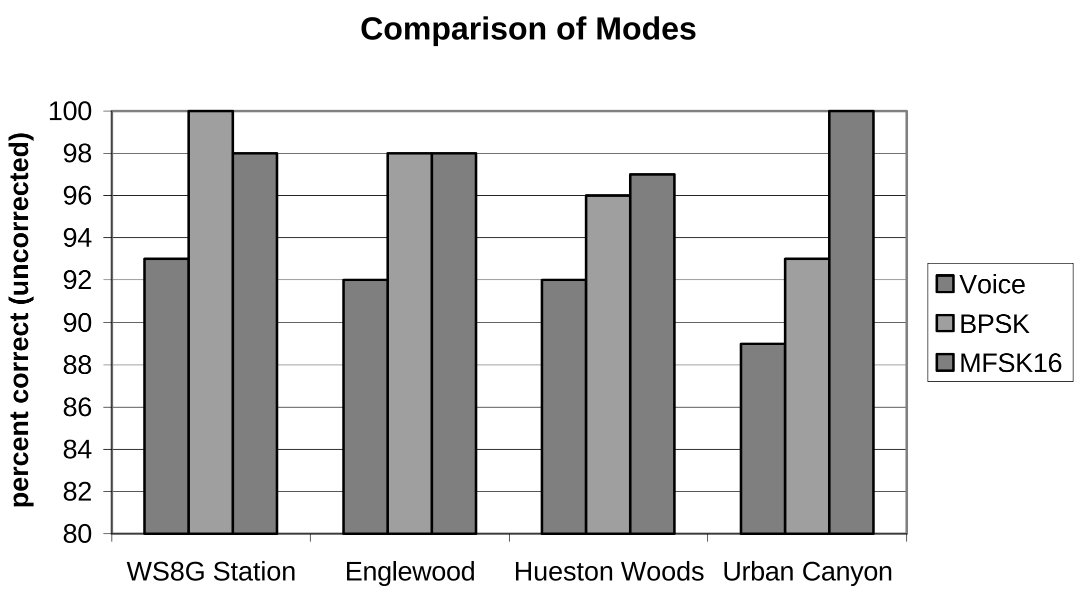


Figure 62. Percent Character Errors – Mode Comparison Overall

An assumption can be made that the human errors in analog voice test performance also degraded performance in comparison with perfect performance. It may be true that up to about 2 percent of errors are "careless" errors. There is insufficient data to suppose either perfect performance by the operators on voice or to suppose that the error rate on voice is the same as that on digital performance.

Several factors contribute to the improved performance of digital communication vs. analog communication. A significant contribution to this error rate is the designed difficulty of distinguishing the spoken words in the test sets. The words were developed to sound alike, not necessarily to look alike in text. This same human factor is also reflected in real world communications, when human voice is used for analog communication.

An additional factor is the time dispersion of the digital signal as opposed to the analog spoken word. Transient atmospheric disturbances have an effect on digital characters, but the same disturbance can entirely render a spoken word meaningless.

Further, an operator's temporary lapse of attention during the analog testing resulted in an unrecoverable error. On the digital testing, the transmitted symbols remained on the screen until scrolling off. Lapsed attention during a digital test could be corrected by looking back at the screen a second time.

V. Conclusions and Recommendations for Further Research

It is practical to construct a medium range emergency communication system using low power transceivers and a lightweight portable Near Vertical Incidence Skywave (NVIS) antenna system on HF radio bands. Communications can be conducted in analog single side band audio, or may utilize one of several COTS digital systems that rely on a laptop computer and the digital signal processing capability of a computer sound card. For this research, radio stations were set up in locations representing the local conditions that could exist for emergency response parties.

Conclusions

The first station pair represents a near line-of-sight (LOS) condition. For this portable setup alone, VHF LOS communication was possible across this distance with similar power output as what was used in the HF experiment. The portable station's antenna was designed in such a way that the ground wave and LOS wave would be reduced in intensity, allowing the bulk of the received energy to be received from the sky wave. The distance and reflective components of the sky wave make it a riskier propagation path, but the communication was still able to succeed.

The second station pair was chosen at a reasonably close distance, but with lots of rock and dirt between the stations. In a 150-foot deep hole at this distance, there would not have been any significant ground wave in the valley. This station represents many of the situations that may occur in rural hilly environments and mountain valleys.

The third station pair was chosen to represent the problems of a radio environment near the radio horizon, and down a hill. It is this sort of environment that suffers from an inability to maintain VHF links even with very tall towers at the base station. It is this same sort of place that suffers from the strong signal degradation from being in a *skip area*.

The fourth station pair was added to simulate the difficult radio environment of an urban canyon. In such an area, VHF and UHF traffic is of little use unless very tall buildings have working repeaters. Even when such repeaters exist, they may be jammed with too much traffic during an emergency. This fourth station pair was added to test the idea of using sky waves to communicate from the surface streets surrounded by the concrete and metal of a modern city. Such communication can be conducted even when the tops of the buildings are inaccessible and power systems have been turned off.

The result of all station pairs was a resounding success for all communication modes. The received signal strength was usable in all modes. Error rates were comparable to other forms of radio communication. Voice analog signals had an word recognition error rate of between eight and twelve percent. Digital mode error rates were all less than 5 percent.

Conclusions can be drawn about the human element in these experiments. As a physician, these elements are amongst the most fascinating of the results. Almost a two percent error rate can be attributed to the two operators in their choice of right answers for the digital portions of the testing. Nothing can be inferred about the error rate involving audio communication from this, other than a strong probability that the error rate was not zero.

While an examination of the causes of human error is outside the scope of this thesis, the existence of such error must be recognized as affecting the results of the experiment. This is as it should be, because human operators of the system are expected in any emergency communication system.

Recommendations for Further Research

The strength of the signals begs work at lower power levels. One watt or even a half-watt are reasonable goals for further experiments. Such power levels would improve efficiency of communications systems that need to be carried in a backpack. This would be the direction one could go if there was need for a very lightweight radio system to be carried while running long distances, or climbing rock escarpments.

Other goals for further research would be to apply these antennas to spread spectrum communication. While the bandwidth of the HF frequencies is not very large compared with the available bandwidth at higher frequencies, enough is available to pass small data streams across perhaps a tenth of a megahertz up to a full megahertz. With a very small power level, such communications may not be easily discovered. It is likely that such a data stream spread only over the available audio bandwidth of an amateur radio transceiver and a commercial computer sound card could be identified, but when spread out 50 times more thinly, it will be more difficult.

Appendix A – NEC Input Cards

From these wire lengths, and orientation, the model results can be replicated. A copy of the computer files with these values will be held by Dr Terzuoli, the Thesis Advisor.

40 M Vertical

```
CM
CE
GW 1 20 0 0 0.1 0 0 32.75 0.0010565
GW 2 10 0 0 0.1 32.75 0 0.1 0.0010565
GW 3 10 0 0 0.1 -32.75 0 0.1 0.0010565
GW 4 10 0 0 0.1 0 32.75 0.1 0.0010565
GW 5 10 0 0 0.1 0 -32.75 0.1 0.0010565
GW 30901 1 9901.0000 9901.0000 9901.0000 9901.0001 9901.0001 9901.0001 .00001
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 30901 1 0 1 0
LD 5 1 1 20 5.8001E7
LD 5 2 1 10 5.8001E7
LD 5 3 1 10 5.8001E7
LD 5 4 1 10 5.8001E7
LD 5 5 1 10 5.8001E7
NT 30901 1 1 1 0 0 0 1 0 0
FR 0 9 0 0 7 0.05
RP 0 1 360 1000 66 1 1 1
FR 0 9 0 0 7 0.05
RP 0 181 1 1000 -90 0 1 1
EN
```

40 M Loop at 33 feet

```
CM
CE
GW 1 3 0.2 0 33 0 0.2 33 0.0013321
GW 2 10 0.2 0 33 35.2 0 33 0.0013321
GW 3 10 35.2 0 33 35.2 35.2 33 0.0013321
GW 4 10 35.2 35.2 33 0 35.2 33 0.0013321
GW 5 10 0 35.2 33 0 0.2 33 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 2 0 1 0
LD 5 1 1 3 5.8001E7
LD 5 2 1 10 5.8001E7
LD 5 3 1 10 5.8001E7
```

```
LD 5 4 1 10 5.8001E7
LD 5 5 1 10 5.8001E7
FR 0 9 0 0 7 0.05
RP 0 1 360 1000 66 1 1 1
FR 0 9 0 0 7 0.05
RP 0 181 1 1000 -90 0 1 1
EN
```

40 M Loop at 10 feet

```
CM
CE
GW 1 3 0.2 0 10 0 0.2 10 0.0013321
GW 2 10 0.2 0 10 34.75 0 10 0.0013321
GW 3 10 34.75 0 10 34.75 34.75 10 0.0013321
GW 4 10 34.75 34.75 10 0 34.75 10 0.0013321
GW 5 10 0 34.75 10 0 0.2 10 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 2 0 1 0
LD 5 1 1 3 5.8001E7
LD 5 2 1 10 5.8001E7
LD 5 3 1 10 5.8001E7
LD 5 4 1 10 5.8001E7
LD 5 5 1 10 5.8001E7
FR 0 9 0 0 7 0.05
RP 0 1 360 1000 66 1 1 1
FR 0 9 0 0 7 0.05
RP 0 181 1 1000 -90 225 1 1
EN
```

40 M Loop at 5 feet

```
CM
CE
GW 1 3 0.2 0 5 0 0.2 5 0.0013321
GW 2 10 0.2 0 5 34.25 0 5 0.0013321
GW 3 10 34.25 0 5 34.25 34.25 5 0.0013321
GW 4 10 34.25 34.25 5 0 34.25 5 0.0013321
GW 5 10 0 34.25 5 0 0.2 5 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 2 0 1 0
LD 5 1 1 3 5.8001E7
LD 5 2 1 10 5.8001E7
LD 5 3 1 10 5.8001E7
```

```
LD 5 4 1 10 5.8001E7
LD 5 5 1 10 5.8001E7
FR 0 9 0 0 7 0.05
RP 0 1 360 1000 66 1 1 1
FR 0 9 0 0 7 0.05
RP 0 181 1 1000 -90 135 1 1
EN
```

40 M Dipole at 33 feet

```
CM
CE
GW 1 21 0 32.9 33 0 -32.9 33 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 11 0 1 0
LD 5 1 1 21 5.8001E7
FR 0 9 0 0 7 0.05
RP 0 1 360 1000 66 1 1 1
FR 0 9 0 0 7 0.05
RP 0 181 1 1000 -90 0 1 1
EN
```

40 M Dipole at 10 feet

```
CM
CE
GW 1 21 0 33 10 0 -33 10 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 11 0 1 0
LD 5 1 1 21 5.8001E7
FR 0 9 0 0 7 0.05
RP 0 1 360 1000 66 1 1 1
FR 0 9 0 0 7 0.05
RP 0 181 1 1000 -90 0 1 1
EN
```

40 M Dipole at 5 feet

```
CM
CE
GW 1 21 0 33 5 0 -33 5 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 11 0 1 0
```

```
LD 5 1 1 21 5.8001E7
FR 0 9 0 0 7 0.05
RP 0 1 360 1000 66 1 1 1
FR 0 9 0 0 7 0.05
RP 0 181 1 1000 -90 0 1 1
EN
```

40 M and 80 M Double Loop at 33 feet

```
CM
CE
GW 1 3 0.5 0 33 0 0.5 33 0.0013321
GW 2 10 0.5 0 33 34.5 0 33 0.0013321
GW 3 10 34.5 0 33 73 0 33 0.0013321
GW 4 20 73 0 33 73 73 33 0.0013321
GW 5 20 73 73 33 0 73 33 0.0013321
GW 6 10 0 73 33 0 34.5 33 0.0013321
GW 7 10 0 34.5 33 0 0.5 33 0.0013321
GW 8 10 34.5 0 33 34.5 34.5 33 0.0013321
GW 9 10 34.5 34.5 33 0 34.5 33 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 2 0 1 0
LD 5 1 1 3 5.8001E7
LD 5 2 1 10 5.8001E7
LD 5 3 1 10 5.8001E7
LD 5 4 1 20 5.8001E7
LD 5 5 1 20 5.8001E7
LD 5 6 1 10 5.8001E7
LD 5 7 1 10 5.8001E7
LD 5 8 1 10 5.8001E7
LD 5 9 1 10 5.8001E7
FR 0 8 0 0 3.7 0.5
RP 0 1 360 1000 66 1 1 1
FR 0 8 0 0 3.7 0.5
RP 0 181 1 1000 -90 0 1 1
EN
```

40 M and 80 M Double Loop at 10 feet

```
CM
CE
GW 1 3 0.5 0 10 0 0.5 10 0.0013321
GW 2 10 0.5 0 10 34.5 0 10 0.0013321
GW 3 10 34.5 0 10 73 0 10 0.0013321
GW 4 20 73 0 10 73 73 10 0.0013321
```

```
GW 5 20 73 73 10 0 73 10 0.0013321
GW 6 10 0 73 10 0 34.5 10 0.0013321
GW 7 10 0 34.5 10 0 0.5 10 0.0013321
GW 8 10 34.5 0 10 34.5 34.5 10 0.0013321
GW 9 10 34.5 34.5 10 0 34.5 10 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 2 0 1 0
LD 5 1 1 3 5.8001E7
LD 5 2 1 10 5.8001E7
LD 5 3 1 10 5.8001E7
LD 5 4 1 20 5.8001E7
LD 5 5 1 20 5.8001E7
LD 5 6 1 10 5.8001E7
LD 5 7 1 10 5.8001E7
LD 5 8 1 10 5.8001E7
LD 5 9 1 10 5.8001E7
FR 0 8 0 0 3.7 0.5
RP 0 1 360 1000 66 1 1 1
FR 0 8 0 0 3.7 0.5
RP 0 181 1 1000 -90 225 1 1
EN
```

40 M and 80 M Double Loop at 5 feet

```
CM
CE
GW 1 3 0.5 0 5 0 0.5 5 0.0013321
GW 2 10 0.5 0 5 33 0 5 0.0013321
GW 3 10 33 0 5 73 0 5 0.0013321
GW 4 20 73 0 5 73 73 5 0.0013321
GW 5 20 73 73 5 0 73 5 0.0013321
GW 6 10 0 73 5 0 33 5 0.0013321
GW 7 10 0 33 5 0 0.5 5 0.0013321
GW 8 10 33 0 5 33 33 5 0.0013321
GW 9 10 33 33 5 0 33 5 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 2 0 1 0
LD 5 1 1 3 5.8001E7
LD 5 2 1 10 5.8001E7
LD 5 3 1 10 5.8001E7
LD 5 4 1 20 5.8001E7
LD 5 5 1 20 5.8001E7
LD 5 6 1 10 5.8001E7
```

```
LD 5 7 1 10 5.8001E7
LD 5 8 1 10 5.8001E7
LD 5 9 1 10 5.8001E7
FR 0 8 0 0 3.7 0.5
RP 0 1 360 1000 66 1 1 1
FR 0 8 0 0 3.7 0.5
RP 0 181 1 1000 -90 135 1 1
EN
```

40 M and 80 M Crossed Dipole at 33 feet

```
CM
CE
GW 1 3 -0.5 -0.5 33 0.5 0.5 33 0.0013321
GW 2 10 -32.75 0 33 -0.5 -0.5 33 0.0013321
GW 3 10 32.75 0 33 0.5 0.5 33 0.0013321
GW 4 20 0 -64 33 -0.5 -0.5 33 0.0013321
GW 5 20 0 64 33 0.5 0.5 33 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 2 0 1 0
LD 5 1 1 3 5.8001E7
LD 5 2 1 10 5.8001E7
LD 5 3 1 10 5.8001E7
LD 5 4 1 20 5.8001E7
LD 5 5 1 20 5.8001E7
FR 0 9 0 0 7 0.05
RP 0 1 360 1000 66 1 1 1
FR 0 9 0 0 7 0.05
RP 0 181 1 1000 -90 0 1 1
EN
```

40 M and 80 M Crossed Dipole at 10 feet

```
CM
CE
GW 1 3 -0.5 -0.5 10 0.5 0.5 10 0.0013321
GW 2 10 -33 0 10 -0.5 -0.5 10 0.0013321
GW 3 10 33 0 10 0.5 0.5 10 0.0013321
GW 4 20 0 -64 10 -0.5 -0.5 10 0.0013321
GW 5 20 0 64 10 0.5 0.5 10 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 2 0 1 0
LD 5 1 1 3 5.8001E7
LD 5 2 1 10 5.8001E7
```

```
LD 5 3 1 10 5.8001E7
LD 5 4 1 20 5.8001E7
LD 5 5 1 20 5.8001E7
FR 0 8 0 0 3.7 0.5
RP 0 1 360 1000 66 1 1 1
FR 0 8 0 0 3.7 0.5
RP 0 181 1 1000 -90 270 1 1
EN
```

40 M and 80 M Crossed Dipole at 5 feet

```
CM
CE
GW 1 3 -0.5 -0.5 5 0.5 0.5 5 0.0013321
GW 2 10 -32.75 0 5 -0.5 -0.5 5 0.0013321
GW 3 10 32.75 0 5 0.5 0.5 5 0.0013321
GW 4 20 0 -63.5 5 -0.5 -0.5 5 0.0013321
GW 5 20 0 63.5 5 0.5 0.5 5 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 2 0 1 0
LD 5 1 1 3 5.8001E7
LD 5 2 1 10 5.8001E7
LD 5 3 1 10 5.8001E7
LD 5 4 1 20 5.8001E7
LD 5 5 1 20 5.8001E7
FR 0 8 0 0 3.7 0.5
RP 0 1 360 1000 66 1 1 1
FR 0 8 0 0 3.7 0.5
RP 0 181 1 1000 -90 270 1 1
EN
```

40 M Loop with reflector at 10 feet

```
CM
CE
GW 1 3 0.2 0 10 0 0.2 10 0.0013321
GW 2 10 0.2 0 10 34.75 0 10 0.0013321
GW 3 10 34.75 0 10 34.75 34.75 10 0.0013321
GW 4 10 34.75 34.75 10 0 34.75 10 0.0013321
GW 5 10 0 34.75 10 0 0.2 10 0.0013321
GW 6 10 -1 -1 0.02 35.75 -1 0.02 0.0013321
GW 7 10 35.75 -1 0.02 35.75 35.75 0.02 0.0013321
GW 8 10 35.75 35.75 0.02 -1 35.75 0.02 0.0013321
GW 9 10 -1 35.75 0.02 -1 -1 0.02 0.0013321
GS 0 0 .30479
GE 1
```

```
GN 2 0 0 0 13.0 0.005
EX 0 1 2 0 1 0
LD 5 1 1 3 5.8001E7
LD 5 2 1 10 5.8001E7
LD 5 3 1 10 5.8001E7
LD 5 4 1 10 5.8001E7
LD 5 5 1 10 5.8001E7
LD 5 6 1 10 5.8001E7
LD 5 7 1 10 5.8001E7
LD 5 8 1 10 5.8001E7
LD 5 9 1 10 5.8001E7
FR 0 9 0 0 7 0.05
RP 0 1 360 1000 66 1 1 1
FR 0 9 0 0 7 0.05
RP 0 181 1 1000 -90 225 1 1
EN
```

40 M Dipole with reflector at 10 feet

```
CM
CE
GW 1 21 0 33 10 0 -33 10 0.0013321
GW 2 20 0 34 0.02 0 -34 0.02 0.0013321
GS 0 0 .30479
GE 1
GN 2 0 0 0 13.0 0.005
EX 0 1 11 0 1 0
LD 5 1 1 21 5.8001E7
LD 5 2 1 20 5.8001E7
FR 0 9 0 0 7 0.05
RP 0 1 360 1000 66 1 1 1
FR 0 9 0 0 7 0.05
RP 0 181 1 1000 -90 0 1 1
EN
```

Appendix B – Word Lists

LIST 1

1. LATE
2. LEAN
3. HAD
4. SPEED
5. GROSS
6. BUST
7. REEL
8. SLAP
9. HALF
10. CHASE
11. GRADE
12. TRIP
13. CREEP
14. FADE
15. SUN
16. PLACE
17. CAME
18. CHICKS
19. SLANT
20. LEG
21. MAZE
22. RAISE
23. HUT
24. JUDGE
25. LATCH
26. NET
27. FLANK
28. SEAT
29. KEEN
30. WISH
31. CLASP
32. SUMP
33. PATH
34. BLADE
35. FAN
36. LOOSE
37. CHAFF
38. FEET
39. CRASHED
40. HOLD
41. NODE
42. GATE
43. FIN
44. SKIP
45. PACE
46. MADE
47. GULPS
48. MIST
49. LID
50. SURF

LIST 2

1. LAID
2. LEAD
3. HATCH
4. SPEECH
5. GROPE
6. BUDGE
7. READ
8. SLAM
9. HAVE
10. CHANGE
11. GRAZE
12. TRICK
13. CREAM
14. PHASE
15. SUNK
16. PLANE
17. CASE
18. CHIPS
19. SLASH
20. LED
21. MAIN
22. RAID
23. HUNG
24. JUNK
25. LAND
26. NEST
27. FLAP
28. SEEM
29. KEEP
30. WIND
31. CLAMP
32. SUCH
33. PAD
34. BLAZE
35. FAT
36. LOOP
37. CHAP
38. FIELD
39. CRACKED
40. HOSE
41. NOTE
42. GAZE
43. FILL
44. SKIM
45. PAVE
46. MATE
47. GUNS
48. MIX
49. LINK
50. SURGE

LIST 3

1. LANE
2. LEAK
3. HASH
4. SPEAK
5. GROVE
6. BUMP
7. REACH
8. SLAB
9. HANG
10. CHAIN
11. GREAT
12. TRIM
13. CREEK
14. FACE
15. SUB
16. PLATE
17. CAGE
18. CHILLS
19. SLACK
20. LESS
21. MAKE
22. RATE
23. HUNT
24. JUMP
25. LAP
26. NEXT
27. FLAT
28. CEASE
29. KEYS
30. WING
31. CLAP
32. SOME
33. PAST
34. BLAME
35. FAST
36. LUBE
37. CHAT
38. FEED
39. CRAMPED
40. HOME
41. NOSE
42. GAIN
43. FIFTH
44. SKID
45. PAYS
46. MALE
47. GULLS
48. MID
49. LIFT
50. SEARCH

TEST ANSWER SHEET
List Number: _______ DATE:________ OP ______ Distance _____ Freq ______ Mode __________

INSTRUCTION: Circle word heard. If not certain, guess.

1. LAID	LATE	LANE	26. NET	NEST	NEXT
2. LEAN	LEAD	LEAK	27. FLAP	FLAT	FLANK
3. HASH	HATCH	HAD	28. SEEM	CEASE	SEAT
4. SPEECH	SPEAK	SPEED	29. KEEP	KEEN	KEYS
5. GROSS	GROVE	GROPE	30. WISH	WIND	WING
6. BUST	BUDGE	BUMP	31. CLASP	CLAP	CLAMP
7. READ	REEL	REACH	32. SOME	SUMP	SUCH
8. SLAB	SLAP	SLAM	33. PATH	PAD	PAST
9. HANG	HALF	HAVE	34. BLADE	BLAZE	BLAME
10. CHASE	CHANGE	CHAIN	35. FAT	FAN	FAST
11. GRAZE	GREAT	GRADE	36. LOOSE	LUBE	LOOP
12. TRIP	TRIM	TRICK	37. CHAP	CHAFF	CHAT
13. CREEP	CREAM	CREEK	38. FEET	FIELD	FEED
14. PHASE	FACE	FADE	39. CRAMPED	CRACKED	CRASHED
15. SUN	SUNK	SUB	40. HOSE	HOLD	HOME
16. PLATE	PLACE	PLANE	41. NODE	NOSE	NOTE
17. CASE	CAME	CAGE	42, GATE	GAZE	GAIN
18. CHICKS	CHIPS	CHILLS	43. FIFTH	FILL	FIN
19. SLACK	SLASH	SLANT	44. SKIM	SKID	SKIP
20. LESS	LED	LEG	45. PACE	PAVE	PAYS
21. MAZE	MAKE	MAIN	46. MALE	MADE	MATE
22. RAID	RATE	RAISE	47. GUNS	GULPS	GULLS
23. HUNG	HUT	HUNT	48. MIST	MIX	MID
24. JUDGE	JUNK	JUMP	49. LIFT	LINK	LID
25. LAP	LAND	LATCH	50. SURF	SURGE	SEARCH

Appendix C - NVIS Preflight

Equipment:

- Antenna
  - Coax
  - Wires
  - Center
  - Supports
- FT 817
  - Battery (charged) or power supply
  - Microphone
  - Soundcard Adaptor and extra stereo wire
- Papers
  - Examiner's sheet
  - 3 data forms
  - Data form with info: Date, List #, Distance, Mode
- Computer
  - Program loaded
  - Battery charged
  - Battery charger

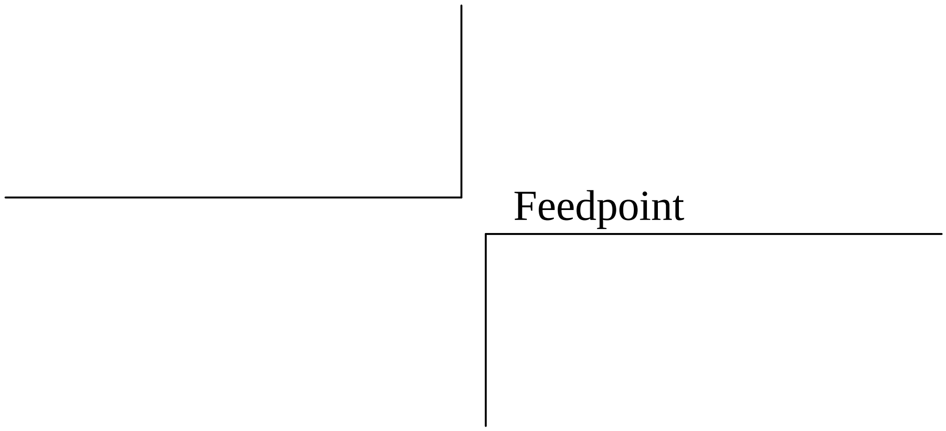
Voice (SSB) Checklist:

- Microphone plugged in
- Radio on LSB
- Frequency double checked

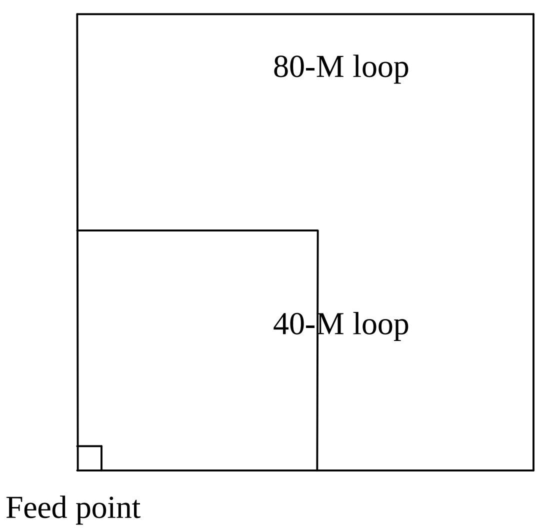
Digital Checklist

- Microphone out, Soundcard wires correctly attached
- Radio on DIG (or USB)
- Frequency double checked
- Computer on
- Get log file ready
  - Open streamlog.txt
  - Select all (Edit, Select All)
  - Delete (Edit, Delete)
  - File, Save
  - Close streamlog.txt (which is now empty)
- Load Stream Program
  - Set for USB
  - Mode set for PSK31 (Or MFSK16)
- Communicate and collect data
- Close Stream Program
- Save log file
  - Open streamlog.txt
  - File, Save As _______ (like fb0402nvis8milesurban.txt)
- Send data to WS8G
  - Email data file
  - Hand over the data sheets

Appendix D – Dual Band Antenna Configurations



Crossed Dipole Configuration



Double Loop Configuration

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Vita

Colonel Richard Allnutt, MD, MPH, is a Chief Flight Surgeon and a senior Air Force research physician. His assignments have included Langley AFB in Virginia, Brooks AFB in Texas, Hahn AB in Germany, and Wright-Patterson AFB in Ohio.

Dr. Allnutt has served as the Chief of Flight Medicine at a busy base hospital, as the Chief of Medical Research Requirements for Air Combat Command, as the Chief of Aerospace Medicine for Air Force Material Command, and as the Chief of Experimental Safety for the Human Effectiveness Directorate in the Air Force Research Laboratory.

Dr. Allnutt's overarching purpose in pursuing the Master of Science degree is a desire to speak with clarity in both the technical and medical research communities. He hopes, by example, a number of young research physicians will follow these footsteps and also obtain a technical degree to round out degrees in epidemiology and medicine.

This degree was designed to combine Dr Allnutt's medical research and amateur radio background. The thesis combines an exploration of human factors, electrical engineering, and practical radio experience to characterize an achievable emergency radio communication system that *will* work when nothing else will.

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14. ABSTRACT
The NVIS system characterized in this workis designed to eliminate skip propagation by optimizing the design for contiguous coverage. The NVIS technique involves use of transmission and receiving antennas that create nearly vertical propagation and continuous coverage from the transmitter to a distance of 200 miles.
Man portable, very low power transceivers (5 watts maximum) and horizontal dipole antennas five feet above the ground are used in an NVIS communication system for this work. The system is designed for the purpose of supporting communication with emergency workers in areas where other communication is difficult. Digital and analog effectiveness are compared at this low power range, and the human factors of communication error are described.

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